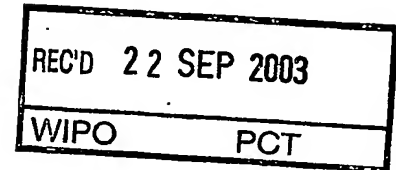


PCT/NZ03/00184



## CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 20 August 2002 with an application for Letters Patent number 520895 made by Glycox Corporation Limited.

I further certify that pursuant to a claim under Section 24(1) of the Patents Act 1953, a direction was given that the application proceed in the name of PROTEMIX CORPORATION LIMITED.

Dated 10 September 2003.

**PRIORITY  
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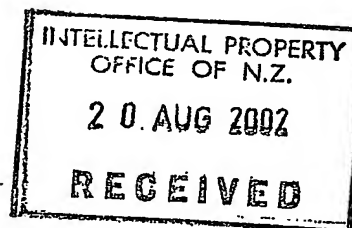
Neville Harris  
Commissioner of Patents

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**SUBSTITUTION OF APPLICANT  
UNDER SECTION 24**

**NEW ZEALAND**

**PATENTS ACT, 1953**



**PROVISIONAL SPECIFICATION**

**"Dosage Forms and Related Therapies"**

We, GLYCOX CORPORATION LIMITED, a company duly incorporated under the laws of New Zealand of Level 4, 41 Shortland Street, Auckland, New Zealand, do hereby declare this invention to be described in the following statement:

## FIELD OF THE INVENTION

The present invention relates to uses for preparing dosage forms, such forms and their use in methods of

- (A) reversing damage in a mammal (I) being a diabetic human being or other diabetic mammal or (II) being a human being or other mammal with copper levels capable of diminishment ("the patient")  
cardiac structure damage selected from one or more of atrophy, loss of myocytes, expansion of the extracellular space and increased deposition of extracellular matrix (and its consequences), and/or  
coronary artery structure damage (and its consequences),
  - (B) improving by reversal of damage in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") any one or more systolic function, diastolic function, contractility, recoil characteristics and ejection fraction (e.g. as determined clinically, by ultrasound, MRI or other imaging), and/or
  - (C) reversing by reversal of damage in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") disorders of the heart muscle, macrovascular disease, microvascular disease and plaque rupture of athereomatous lesions of major blood vessels (and the consequences thereof),
- reliant upon, as active ingredient(s), trientine (See Martindale 33<sup>rd</sup> edition, 1025.3), salts of trientine and/or metabolites thereof.

The invention also consists in methods of reversing in a patient at least some of any damage arising from diabetic kidney disease, diabetic nephropathy and/or copper accumulation in the kidney, and/or reversing in a patient at least some of any damage to the renal arteries reliant upon the abovementioned active ingredient(s).

Reference to "copper levels capable of diminishment" may mean elevated copper levels but not necessarily so. The term "capable of diminishment" refers to copper values readily scavenged by the trientine chelating moiety as opposed, we believe, to those copper values less readily scavenged (likely non interstitially located copper values).

Included in the present invention are dosage forms of the active ingredient(s) and relates to related uses (including uses in the preparation of pharmaceutical compositions of trientine, salts of trientine and/or metabolites thereof). Such dosage forms are indicated for at least both diabetic and diabetes predisposed patients and at least patients having copper level capable of diminishment by chelation.

By way of background the following can be stated in respect of diabetic heart disease in the human being,

1. Worldwide prevalence of diabetes is increasing. Number of cases of type 2 diabetes projected to increase from 135 million in 2000 to more than 300 million in 2025. Increase is related to ageing of the population, increasing obesity, and low socio-economic status. See, WHO. The World Health Report 1997.
2. Mortality from diabetes has increased over the last decade whereas mortality from cardiovascular disease, stroke, and malignant diseases has remained static or declined. See, US Centre for Health Studies.
3. Causes of premature mortality in type 2 diabetes comprise cardiovascular disease, 58%; cerebrovascular disease, 12%; nephropathy, 3%; diabetic coma, 1%; malignancy, 11%; and infections 4%. See, Pickup J, Williams G eds. Handbook of diabetes, 2nd edition, 1999; p 24.
4. Diabetic heart disease is characterised by more severe coronary artery disease at a younger age, a 4-fold increased frequency of heart failure post-acute myocardial infarction and a disproportionate increase in left ventricular hypertrophy. See Struthers AD, Morris AD, Lancet 2002;359:1430-2.
5. Patients with type 2 diabetes manifest a disproportionate increase in mortality within the first 24-hours post-acute myocardial infarction. Acute intervention can ameliorate this risk. See, Malmberg K Br Med J 1997;314:1512-5.

Much of the above is equally applicable to diabetic coronary artery structure.

PCT/NZ99/00161 (published as WO00/18392 on 6 April 2000) has disclosed a method of treating a mammalian patient predisposed to and/or suffering from diabetes mellitus with a view to minimising the consequences of macrovascular and microvascular damage to the patent which comprises, in addition to any treatment in order to control

blood glucose levels, at least periodically inhibiting or antagonizing fructosamine oxidase enzyme activity in the patient. An assay for such activity is disclosed in their PCT/NZ99/00160 (published as WO00/18891 on 6 April 2000).

A range of different agents capable of acting as fructosamine oxidase inhibitors and/or antagonists were disclosed in PCT/NZ99/00161. These included copper chelating agents, substrate analogues and hydrazine compounds.

The full contents of the aforementioned specifications are here included by way of reference.

We have hypothesised that reduction in available free copper does have an affect in preventing macrovascular, microvascular and/or toxic/metabolic diseases of the kind hereinafter exemplified and in tissue repair processes. This is irrespective of the glucose metabolism of the patient.

We have also hypothesized that cardiovascular accumulation of redox-active transition metal ions is responsible for many of the adverse outcomes in diabetes. Under physiological conditions, injury to a target organ is sensed by distant stem cells, which migrate to the site of damage then undergo alternate stem cell differentiation; these events promote structural and functional repair. However, the accumulation of redox-active transition metals, particularly copper in cardiac or vascular tissues in subjects with diabetes is accompanied by a suppression of the normal tissue regeneration effected by the migration of stem cells. Elevated tissue levels of copper suppress these normal biological behaviours of such undifferentiated cells. Conditions occurring in the context of diabetes or impaired glucose tolerance, in which the suppression of normal stem cell responses can cause impairment of normal tissue responses, include the following:

1. Cardiac failure
2. Acute myocardial infarction
3. Wound healing and ulceration
4. Tissue damage caused by infection
5. Diabetic kidney damage

Conditions in which therapy to lower copper values in diabetic patients (ie; with IGT or Type 2 Diabetes Mellitus) is liable to prove beneficial include at least the following:

### 1. HEART FAILURE IN THE CONTEXT OF DIABETES

Significant regeneration of cardiac tissues can occur within a few days of cardiac transplantation. The likely mechanism is migration of stem cells from extra-cardiac sites to the heart, with subsequent differentiation of such cells into various specialized cardiac cells, including myocardial, endothelial and coronary vascular cells. We believe that copper accumulation in cardiac tissues is likely to severely impair these regenerative responses. Hence a role for acute intravenous therapy with a copper chelator in the treatment of diabetic heart failure.

### 2. MYOCARDIAL INFARCTION IN THE CONTEXT OF DIABETES.

Myocardial infarction is accompanied by proliferation of cells in the ventricular myocardium when MI occurs in the context of diabetes, the presence of elevated tissue levels of redox-active transition metals suppresses normal stem cell responses, resulting in impaired structural and functional repair of damaged tissues. Up to 20% of cells in the heart may be replaced by stem cell migration from extra-ventricular sites, as soon as four days after cardiac transplantation. These observations suggest that treatment of AMI in the context of diabetes will be improved by acute (if necessary, parenteral) as well as by subsequent chronic administration of chelators. The mechanism of the impairment of cardiac function in diabetes is likely a toxic effect of accumulated transition metals on tissue dynamics, resulting in impaired tissue regeneration caused in turn by suppression of normal stem cell responses, which mediate physiological tissue regeneration by migration to damaged tissue from external sites.

### 3. WOUND HEALING AND ULCERATION IN THE CONTEXT OF DIABETES

The processes of normal tissue repair require intervention of mobilizing stem cells, which effect repair of the various layers of blood vessels, for example. We believe that an accumulation of transition metals (particularly copper) in vascular tissues causes the impaired tissue behaviour characteristic of diabetes, including impaired wound repair following surgery or trauma, and the exaggerated tendency to ulceration and poor healing of established ulcers. We believe that the treatment of diabetics with copper chelators

before they undergo surgery, or in the context of traumatic tissue damage, is likely to be of benefit. It is probable that surgery in diabetics would have a better outcome if excess transition metals were removed from blood vessels prior to surgery. This may need to be accomplished on either an acute basis (with parenteral therapy) or on a more chronic basis (with oral therapy) prior to actual surgery.

#### 4. SOFT TISSUE DAMAGE RESULTING FROM INFECTION AND OCCURRING IN THE CONTEXT OF DIABETES OR IMPAIRED GLUCOSE TOLERANCE

We believe the processes of normal tissue repair following infection require intervention of mobilized stem cells, which migrate to sites of tissue damage to effect tissue regeneration and repair, for example, of the various layers of blood vessels. Such tissue damage will be impaired by suppressed stem cell responses, such as those caused by the build up of redox-active transition metals (particularly copper) in tissues, for examples the walls of blood vessels.

#### 5. KIDNEY DAMAGE OCCURRING IN THE CONTEXT OF DIABETES

We believe that impaired stem cell responses in the kidneys of diabetics contribute to diabetic nephropathy and renal failure. We believe that treatment of diabetics having kidney failure by administration of a copper chelator will improve organ regeneration by restoring normal tissue healing by allowing stem cells to migrate and differentiate normally.

However, even in the non diabetic mammal and even in a mammal without a glucose mechanism abnormality, we have hypothesised a reduction in extra-cellular copper values is advantageous in that such lower levels will lead to one or both a reduction in copper mediated tissue damage and improved tissue repair by restoration of normal tissue stem cell responses.

In our own studies (using the streptozocin-diabetic (STZ) rat model) we have found a high frequency of tissue damage in the heart tissue and coronary artery tissue in severely diabetic animals. This reflects what is found in man.

We now more firmly take the view that copper values (and particularly copper II) not bound internally of cells is available to mediate (together with available reducing substances) the generation of damaging free radicals that have a role in both tissue damage and impairment of stem cell mediated repair of such tissue. This is irrespective of diabetic status but we believe is more prevalent in diabetic rats and other mammals including human beings.

In respect of such damage and repair impairment we propose a diminishment in available free copper values as being an appropriate preventive and/or treatment approach for diabetic patients or any patient and particularly a patient (not suffering Wilson Disease) who has elevated copper levels.

Our agent of choice for such diminishment is trientine (ie; TETA), preferably as an acid addition salt.

Alternative names for trientine include N,N'-Bis(2-aminoethyl)-1,2-ethanedi-amine; triethylenetetramine ("TETA"); 1,8-diamino-3,6-diazaoctane; 3,6-diazaoctane-1,8-diamine; 1,4,7,10-tetraazadecane; trien; TETA; TECZA and triene.

Reference made herein to "trientine" refers to TETA. Preferably the trientine is rendered less basic (eg; as a moiety in a delivery form) but can include analogues thereof which are prodrugs of the active copper chelating moiety or a copper chelating metabolite of trientine. Salts of trientine (which optionally can be salts of a prodrug of the trientine copper chelating moiety or metabolite) are preferably acid addition salts such as, for example, those of suitable mineral or organic acids.

Salts of trientine (such as acid addition salts, eg; trientine dihydrochloride) act as copper-chelating agents, which aids the elimination of copper from the body by forming a stable soluble complex that is readily excreted by the kidney.

Trientine, a strongly basic moiety, with its multiple nitrogens can be converted into a large number of suitable associated acid addition salts using an acid, for example, by reaction of stoichiometrically equivalent amounts of trientine and of the acid in an inert solvent such as ethanol or water and subsequent evaporation if the dosage form is best formulated from a dry salt. Possible acids for this reaction are in particular those which yield physiologically acceptable salts. Thus inorganic acids can be used, e.g. sulfuric



acid, nitric acid, hydrohalic acids such as hydrochloric acid or hydrobromic acid, phosphoric acids such as orthophosphoric acid, sulfamic acid. Furthermore organic acids, can be used, in particular aliphatic, alicyclic, araliphatic, aromatic or heterocyclic mono- or polybasic carboxylic, sulfonic or sulfuric acids, (e.g. formic acid, acetic acid, propionic acid, pivalic acid, diethylacetic acid, malonic acid, succinic acid, pimelic acid, fumaric acid, maleic acid, lactic acid, tartaric acid, malic acid, citric acid, gluconic acid, ascorbic acid, nicotinic acid, isonicotinic acid, methane- or ethanesulfonic acid, ethanedisulfonic acid, 2-hydroxyethanesulfonic acid, benzenesulfonic acid, p-toluenesulfonic acid, naphthalenemono- and -disulfonic acids and laurylsulfuric acid).

The trientine moieties can also be in the form of quaternary ammonium salts in which the nitrogen atom carries a suitable organic group such as an alkyl, alkenyl, alkynyl or aralkyl moiety.

Preferably the trientine moieties are in the form of a compound or buffered in solution and/or suspension to a near neutral pH much lower than the pH of 14 of trientine itself.

Suitable anions may include citrate, isocitrate,  $\alpha$ -Ketoglutarate, Succinate, Fumarate, Malate, Oxaloacetate, Acetate and pyruvate.

Trientine moieties (preferably delivered as salts of trientine (such as acid addition salts, eg; trientine dihydrochloride) act as copper-chelating agents, which aids the elimination of copper from the body by forming a stable soluble complex that is readily excreted by the kidney.

The presumed site of action of the chelating trientine moiety of a salt such as trientine dihydrochloride is the removal of loosely bound copper from the body and in particular from the cardiac extracellular matrix and the coronary extracellular matrix.

Bioavailabilities of the active species of trientine dihydrochloride after oral administration is low (<10%) due to poor absorption and marked first-pass metabolism. Trientine dihydrochloride and its transformed metabolite, N-acetyl-trientine hydrochloride, are both capable of binding copper, although the chelating activity of the analogue N-acetyl-trientine hydrochloride is significantly lower than trientine dihydrochloride. See, Kodama H. Life Sciences 1997;61:899-907.

Absorption of trientine dihydrochloride is adversely affected by food, mineral supplements and other drugs.

We have now shown in the STZ rat model for both diabetic and non diabetic man a reduction in available free copper does have an affect in reversing in the diabetic rat both (i) cardiac structure damage selected from one or more of atrophy, loss of myocytes, expansion of the extra cellular space and increased deposition of extra cellular matrix (and its consequences) and (ii) coronary artery structure damage (and its consequences). We have also shown amelioration. In so showing reversal of damage in the STZ rat, we have found a dose relativity for man insofar as the copper scavenging into the urine is concerned.

Under physiological conditions we believe injury to the cardiac structure is sensed by distant stem cells, which migrate to the site of damage then undergo alternate stem cell differentiation; these events promote structural and functional repair. However, the accumulation of redox-active transition metals, particularly copper in cardiac tissues and coronary arteries in subjects with diabetes we believe is accompanied by a suppression of the normal tissue regeneration effected by the migration of stem cells. Elevated tissue levels of copper suppress these normal biological behaviours of such undifferentiated cells.

Even in the non diabetic mammal (e.g. without Type 2 Diabetes mellitus) and even in a mammal without a glucose mechanism abnormality (e.g. without IGT), we believe a reduction in extra-cellular copper values is advantageous in that such lower levels will lead to one or both a reduction in copper mediated tissue damage and improved tissue repair by restoration of normal tissue stem cell responses.

Martindale, the Complete Drug Reference, 33<sup>rd</sup> edition, discloses in relation to trientine dihydrochloride (with reference to SYPRINE<sup>TM</sup>) administration by mouth, preferably on an empty stomach. It states in the US the usual initial dose in adults is 0.75 – 1.25 g/day in two or four divided doses increasing to a maximum of 2 g/day (if required) and that daily doses of 1.2 – 2.4 g have been recommended in the UK. It is stated that in children the usual initial dose is 0.5 – 0.75 g/day if required.

The data sheet for SYPRINE® itself (Merck Co, trientine dihydrochloride, indicated for Wilson's Disease) indicates systemic evaluation of dose and/or interval between dose has not been done. However, on limited clinical experience, Merck Co. recommends initial doses of SYPRINE® of 500-700 mg/day for pediatric patients and 750-1250 mg/day for adults given in divided oral doses two, three or four times daily. This may be increased to a maximum of 2000 mg/day for adults or 1500 mg/day for pediatric patients age 112 or under. The daily dose of SYPRINE® should be increased only when the clinical response is not adequate or the concentration of free serum copper is persistently above 20 mcg/dl.

Such dosages for Wilson's Disease are almost always beyond those required for the purposes of the present invention and accordingly we propose lower dosage forms to those hitherto known i.e. the 250 mg to SYPRINE™ oral dosage form.

#### **OBJECT OF THE INVENTION**

It is an object of the present invention to provide oral dosage forms useful for taking advantage of this prospect for the purpose of amelioration of such structure damage and damage reversal all irrespective of whether or not our hypothesis or proposals as to mode of action are correct.

Such damage includes cardiac structure damage selected from one or more of atrophy, loss of myocytes, expansion of the extracellular space and increased deposition of extracellular matrix (and its consequences) and/or coronary artery structure damage selected from at least media damage (the muscle layer) and intima damage (the endothelial layer) (and its consequences), whether or not the hypotheses or proposals as to mode of action are correct.

It is another object to provide uses and dosage forms applicable instead or as well to improve in a human being or other mammal (preferably diabetic and/or with a raised copper level) ("the patient") any one or more of systolic function, diastolic function, contractility, recoil characteristics and ejection fraction (e.g. as determined clinically, by ultrasound, MRI or other imaging), whether or not the hypotheses or proposals as to mode of action are correct.

It is another object of the present invention to provide methods of treatment and related methods, uses and pharmaceutical compositions that ameliorate, prevent or treat any one or more disease states of the cardiovascular tree (including the heart) and dependent organs (eg; retina, kidney, nerves, etc.) exacerbated by elevated non-intracellular free copper values levels, whether or not the hypotheses or proposals as to mode of action are correct.

Reference herein to diseases of the cardiovascular tree and diseases of dependent organs includes any one or more of

- (i) disorders of the heart muscle (cardiomyopathy or myocarditis) such as idiopathic cardiomyopathy, metabolic cardiomyopathy which includes diabetic cardiomyopathy, alcoholic cardiomyopathy, drug-induced cardiomyopathy, ischemic cardiomyopathy, and hypertensive cardiomyopathy,

or

- (ii) atheromatous disorders of the major blood vessels (macrovascular disease) such as the aorta, the coronary arteries, the carotid arteries, the cerebrovascular arteries, the renal arteries, the iliac arteries, the femoral arteries, and the popliteal arteries,

or

- (iii) toxic, drug-induced, and metabolic (including hypertensive and/or diabetic disorders of small blood vessels (microvascular disease) such as the retinal arterioles, the glomerular arterioles, the vasa nervorum, cardiac arterioles, and associated capillary beds of the eye, the kidney, the heart, and the central and peripheral nervous systems,

or

- (iv) plaque rupture of atheromatous lesions of major blood vessels such as the aorta, the coronary arteries, the carotid arteries, the cerebrovascular arteries, the renal arteries, the iliac arteries, the femoral arteries and the popliteal arteries.

The present invention relates to any such ailments and their treatment irrespective (unless otherwise stated) of any diabetic and/or glucose abnormality state of the mammalian patient.

#### STATEMENTS OF INVENTION

Accordingly in a first aspect the present invention consists in, as a or part of a dosage unit, less than 250 mg of trientine dihydrochloride or other administrable trientine form (being less than 250 mg when expressed as trientine dihydrochloride).

Preferably the dosage unit is an oral dosage form.

Accordingly in another aspect the present invention in one aspect consists in a method useful for

- (A) reversing in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") cardiac structure damage selected from one or more of atrophy, loss of myocytes, expansion of the extracellular space and increased deposition of extracellular matrix (and its consequences), and/or coronary artery structure damage (and its consequences),
- (B) improving by reversal of damage in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") any one or more systolic function, diastolic function, contractility, recoil characteristics and ejection fraction (e.g. as determined clinically, by ultrasound, MRI or other imaging),
- (C) reversing in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") disorders of the heart muscle, macrovascular disease, microvascular disease and plaque rupture of athereomatous lesions of major blood vessels (and the consequences thereof), and/or
- (D) reversal of at least some of any damage arising from diabetic kidney disease, diabetic nephropathy and/or copper accumulation in the kidney and/or reversal of at least some of any damage to the renal arteries,

which method comprises or includes the step of administration and/or self administration to the patient of an oral dosage form sufficient to provide effective chelation of copper for an overall diminishment thereof in the patient, said dosage form having as the or an active agent less than 250 mg of trientine dihydrochloride or other salt of trientine when expressed as trientine dihydrochloride.

Preferably the effective amount is of trientine dihydrochloride.

Preferably the dosage of trientine dihydrochloride is fast or sustained release is such that there is always less peaking of the active ingredient in a patient's body than the peaking that results from the 250 mg SYPRINE® type oral dosage forms for Wilson's Disease.

In a further aspect the present invention consists in the use of less than 250 mg of trientine dihydrochloride (or trientine or other salt or derivative thereof when expressed as the dihydrochloride), together with other material(s) (eg; capsuling and/or tableting material including, for example, binders, lubricants, diluents, dispersants, etc.) appropriate for the oral dosage form, in the manufacture of an oral dosage form useful for

- (A) reversing in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") cardiac structure damage selected from one or more of atrophy, loss of myocytes, expansion of the extracellular space and increased deposition of extracellular matrix (and its consequences), and/or coronary artery structure damage (and its consequences),
- (B) improving by reversal of damage in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") any one or more systolic function, diastolic function, contractility, recoil characteristics and ejection fraction (e.g. as determined clinically, by ultrasound, MRI or other imaging),
- (C) reversing some of any damage state in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") selected from or resulting from disorders of the heart muscle, macrovascular disease, microvascular disease and plaque rupture of

athereomatous lesions of major blood vessels (and the consequences thereof), and/or

- (D) reversal of at least some of any damage arising from diabetic kidney disease, diabetic nephropathy and/or copper accumulation in the kidney and/or reversal of at least some of any damage to the renal arteries

In another aspect the present invention consists in an article of manufacture comprising a vessel containing as a dosage form or containing dosage forms a pharmaceutically acceptable trientine moiety, the trientine moiety of the or each dosage form being present at less than 250g when expressed as trientine dihydrochloride; and instructions for use of the trientine moiety for

- (A) reversing in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") cardiac structure damage selected from one or more of atrophy, loss of myocytes, expansion of the extracellular space and increased deposition of extracellular matrix (and its consequences), and/or coronary artery structure damage (and its consequences),
- (B) improving by reversal of damage in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") any one or more systolic function, diastolic function, contractility, recoil characteristics and ejection fraction (e.g. as determined clinically, by ultrasound, MRI or other imaging),
- (C) reversing some of any damage in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") selected from or resulting from disorders of the heart muscle, macrovascular disease, microvascular disease and plaque rupture of athereomatous lesions of major blood vessels (and the consequences thereof), and/or
- (D) reversal of at least some of any damage arising from diabetic kidney disease, diabetic nephropathy and/or copper accumulation in the kidney and/or reversal of at least some of any damage to the renal arteries.

Preferably the dosage unit and/or dosage regimen is such as to provide an effective daily dosage to the patient of the trientine moiety (when expressed as the dihydrochloride salt of trientine, irrespective of whether or not the dosage unit includes that salt) of 4g per day or below.

Prefeably the dosage is from 1 mg to 4g per day if given orally.

A preferred oral dose delivery (cumulative or otherwise) is in the range of from 200mg to 4g per day if given orally.

Preferably the daily dosage is such as to delivery 1.2g per day or below.

In other aspects the dosage delivery is to provide, when expressed as trientine dihydrochloride, a delivery into the patient (irrespective of the dosage included in the dosage unit or units) being administered of from 1 mg to 1.2g per day. If orally administered the soage is from 200 mg to 1.2 per day.

The labeled regimen may recommend a daily dosage (one or more dosage units) below that recommended as aforesaid for Wilson's Disease.

Preferably the dosage is such as to deliver the trientine moiety in a dosage unit that administers the trientine moiety at a pH of from 7.2 to 7.6 (preferably a pH of  $7.4 \pm 0.1$ ).

In a further aspect the present invention consists in **the use** of trientine, at least one salt of trientine and/or at least one metabolite of trientine and/or its salt(s) (the "active agent(s)") together with other material(s) appropriate for the dosage form, **in the manufacture** of a dosage form in an amount of less than 250 mg when expressed as the dihydrochloride useful for improving by reversal of damage in a human being or other mammal at risk (preferably diabetic and/or with a copper level capable of diminishment) ("the patient") any one or more of at least some of any damage arising from diabetic kidney disease, diabetic nephropathy and/or copper accumulation in the kidney and/or reversing at least some of any damage to the renal arteries.

In another aspect the present invention consists in **an article of manufacture** comprising;

packaging material; and



contained within the packaging material a pharmaceutically acceptable trientine moiety in a dosage form, the trientine moiety of the dosage form being present at less than 250g when expressed as trientine dihydrochloride,

wherein the packaging material has a label that indicates that the dosage form can be used for

- (A) reversing in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") cardiac structure damage selected from one or more of atrophy, loss of myocytes, expansion of the extracellular space and increased deposition of extracellular matrix (and its consequences), and/or coronary artery structure damage (and its consequences),
- (B) improving by reversal of damage in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") any one or more systolic function, diastolic function, contractility, recoil characteristics and ejection fraction (e.g. as determined clinically, by ultrasound, MRI or other imaging),
- (C) reversing in (I) a diabetic human being or other diabetic mammal or (II) a human being or other mammal with copper levels capable of diminishment ("the patient") selected from or resulting from disorders of the heart muscle, macrovascular disease, microvascular disease and plaque rupture of atheromatous lesions of major blood vessels (and the consequences thereof), and/or
- (D) reversing at least some of any damage arising from diabetic kidney disease, diabetic nephropathy and/or copper accumulation in the kidney and/or reversing at least some of any of damage to the renal arteries.

Preferably the dosage unit and/or dosage regimen is such as to provide an effective daily dosage to the patient of the trientine moiety (when expressed as the dihydrochloride salt of trientine, irrespective of whether or not the dosage unit includes that salt) of 4g per day or below.

Preferably the dosage is from 1 mg to 4g per day if given orally.

A preferred oral dose delivery (cumulative or otherwise) is in the range of from 200 mg to 4g per day if given orally.

Preferably the daily dosage is such as to delivery 1.2g per day or below.

In other aspects the dosage delivery is to provide, when expressed as trientine dihydrochloride, a delivery into the patient (irrespective of the dosage included in the dosage unit or units) being administered of from 1mg to 1.2g per day. If orally administered the dosage is from 200 mg to 1.2g per day.

The labeled regimen may recommend a daily dosage (one or more dosage units) below that recommended as aforesaid for Wilson's Disease.

Preferably the dosage is such as to delivery the trientine moiety in a dosage unit that administers the trientine moiety at a pH of from 7.2 to 7.6 (preferably a pH of  $7.4 \pm 0.1$ ).

We have determined in our trials referred to hereinafter that a divided dose of 1.2 g/day is effective for and yet (insofar as an instantaneous body level is concerned) in excess of dosage levels to be required chronically in practice for the purpose of amelioration and/or reversal of cardiac structure damage and/or coronary artery structure damage. Such a dose rate of 1.2 g per day is capable of being provided by the use of capsules of 300 mg trientine hydrochloride given half an hour before meals two being given in the morning and two being given at night.

We propose dosage forms, based on the trientine moiety, when expressed as trientine dihydrochloride and preferably being trientine dihydrochloride, of less than 250 mg per dose whether as a tablet (including lozenges, dragees, etc.) or a capsule.

Reference herein to "elevated" in relation to the presence of copper values will include humans having at least 10 mcg free copper/dL of serum when measured as discussed by Merck & Co Inc below.

A measurement of free copper [which equals total plasma copper minus ceruloplasmin-bound copper] can be made using the procedure disclosed in the Merck & Co Inc datasheet ([www.Merck.com](http://www.Merck.com)) for SYPRINE® (trientine dihydrochloride) capsules where they state in respect of the use of trientine dihydrochloride for the copper values excesses of Wilson's Disease:

"The most reliable index for monitoring treatment is the determination of free copper in the serum, which equals the difference between quantitatively determined total copper and ceruloplasmin-copper. Adequately treated patients will usually have less than 10 mcg free copper/dL of serum.

Therapy may be monitored with a 24 hour urinary copper analysis periodically (i.e. every 6-12 months). Urine must be collected in copper-free glassware. Since a low copper diet should keep copper absorption down to less than one milligram a day, the patient probably will be in the desired state of negative copper balance if 0.5 to 1.0 milligram of copper is present in a 24-hour collection of urine".

#### **BREIF DESCRIPTION OF THE DRAWINGS**

We have conducted studies reliant on trientine dihydrochloride in the STZ rat model as well in humans and wish to describe the invention further by reference to the accompanying drawings in which:

**Figure 1** (Figure 1A in colour and **Figure 1B** (the same as Figure 1A) in black and white) shows for the STZ rat model, animals made diabetic for more than six weeks, having damaged cardiac structure with atrophy and loss of myocytes, expansion of the extracellular space, and increased deposition of extracellular matrix, these differences are observed between showing the non diabetic STZ rat cardiac tissue, the untreated diabetic rat tissue and the trientine dihydrochloride treated diabetic rat tissue,

**Figure 2A** shows in STZ diabetic rats compared with non diabetic rats cardiac function impairment that is largely corrected by chronic oral therapy with trientine dihydrochloride,

**Figure 2B** shows functional survival of working hearts arising from the isolated working heart model to form the basis of the data generation for Figure 2A,

**Figure 3** shows how doses of trientine hydrochloride modifies copper excretion in the urine,

**Figure 4** shows the absolute weight change with time of the period of the experiment,

**Figure 5** is a diagram showing the bodyweight of the animals changing over the time period of the experiment,

**Figure 6** shows the glucose levels of the animals changing over the time period of the experiment,

**Figure 7** is a diagram showing cardiac output at various filling pressures,

**Figure 8** is a diagram showing the coronary flow at various filling pressures,

**Figure 8A** is a diagram showing the coronary flow of **Figure 8** normalised to final cardiac weight,

**Figure 9** is a diagram showing the aortic flow with increasing preload,

**Figure 10** is a diagram showing the peak pressure developed in the left ventricle at various filling pressures,

**Figure 11** is a diagram showing the maximal rate of positive change in pressure development in the ventricle in response to increasing preload,

**Figure 12** is a diagram showing the corresponding maximal rate of decrease in ventricular pressure in response to increasing preload,

**Figure 13** shows the maximal rate of increase in pressure in the aortic outflow,

**Figure 14** shows the corresponding maximal rate of decrease in the aortic pressure in response to increasing preload,

**Figure 15** shows the percentage of functionally surviving hearts at each afterload pressure,

**Figure 16** shows the cardiac output in response to increasing afterload,

**Figure 17A** shows the absolute change in coronary flow in response to increasing afterload,

**Figure 17B** shows the increases in coronary flow in response to increasing afterload normalized to heart weight,

**Figure 18** shows the peak pressure developed in the left ventricle in response to increasing afterload,

**Figure 19** shows the maximum rate of positive change in pressure development in the ventricle in response to increasing afterload,

**Figure 20** shows the corresponding maximum rate of decrease in ventricular pressure in response to increasing afterload,

**Figure 21** shows the maximum rate of positive change in pressure within the aortic outflow in response to increasing afterload,

**Figure 22** shows the corresponding maximal rate of decrease in aortic pressure in response to increasing afterload,

**Figure 23A** shows diagrammatically how the extracted heart was attached to the modified apparatus,

**Figure 23B** shows diagrammatically in more detail the extracted heart as it was attached to the modified apparatus,

**Figure 24** shows the urine excretion in diabetic and non diabetic animals in response to increasing doses of trientine,

**Figure 25** shows volume of or an equivalent volume of saline (control) urine excreted in non diabetic and diabetic animals receiving increasing doses of trientine or an equivalent volume of saline,

**Figure 26** shows copper excretion in the urine of diabetic and non diabetic animals receiving increasing doses of trientine or an equivalent volume of saline,

**Figure 27** shows the same information in Figure 26 as urinary copper excretion per gram of bodyweight,

**Figure 28** shows the total amount of copper excreted in non diabetic and diabetic animals administered saline or trientine,

**Figure 29** shows the total amount of copper excreted per gram of bodyweight in animals receiving trientine or saline,

**Figure 30** shows the iron excretion in urine of diabetic and non diabetic animals receiving increasing doses of trientine or an equivalent volume of saline,

**Figure 31** shows the urinary iron excretion per gram of bodyweight in diabetic and non diabetic animals receiving trientine or saline,

**Figure 32** shows the total urinary iron excretion in non diabetic and diabetic animals administered saline,

**Figure 33** shows the total urinary iron excretion per gram of bodyweight in animals receiving trientine or saline,

**Figure 34** shows the percentage of surviving hearts at each afterload pressure,

**Figure 35** is a table comparing the copper and iron excretion in the animals receiving trientine or saline, which is a statistical analysis using a mixed linear model.

**Figure 36** is a plasma concentration-time profiles of trientine after oral administration to four male patients, and

**Figure 37** is a plasma concentration-time profiles of trientine after oral administration to four female patients..

### **DETAILED DESCRIPTION**

In the STZ rat model, animals made diabetic for more than 6 weeks show damaged cardiac structure with atrophy and loss of myocytes, expansion of the extracellular space, and increased deposition of extracellular matrix. These appearances are both ameliorated and reversed by chronic oral therapy with trientine dihydrochloride. See, Figures 1A & 1B.

Using the isolated working heart model, cardiac function is severely impaired in STZ diabetic rats compared with non-diabetic animals. Cardiac dysfunction is largely corrected by chronic oral therapy with trientine hydrochloride. See, Figures 2A & 2B. This is more clearly set out in the experimentation studies below.

### **EXPERIMENTS CONDUCTED**

#### **INTRODUCTION**

Increased tissue copper has been implicated in mechanisms leading to diabetic nerve damage. We therefore hypothesized that tissue accumulation of trace metals might play a role in the mechanisms of diabetic damage in other tissues. Evidence from our earlier studies showed that 6 months of treatment with trientine appears to protect the hearts of diabetic Wistar rats from development of diabetic damage (cardiomyopathy) as judged by histology. In this study we investigated the doses of trientine required for copper and iron to be excreted in the urine, and also any possible difference between the excretion of these metals in diabetic and nondiabetic animals.

## AIM

1. To compare the excretion profiles of copper and iron in the urine of normal and diabetic rats after acute intravenous administration of varying doses of trientine.
2. To ascertain that the acute intravenous administration of trientine has no acute adverse cardiovascular side effects.

## METHODS

All methods used in this study were approved by the University of Auckland Animal Ethics Committee and were in accordance with The Animals Protection Act and Regulations of New Zealand.

### Induction of diabetes.

Male Wistar rats ( $n = 28$ ,  $303 \pm 2.9$  g) were divided randomly into diabetic and nondiabetic groups. Following induction of anesthesia (5% halothane and  $2\text{ l}\cdot\text{min}^{-1}$   $\text{O}_2$ ), animals in the diabetic group received a single intravenous dose of streptozotocin (STZ,  $55 \text{ mg}\cdot\text{kg}^{-1}$  body weight, Sigma; St. Louis, MO) in 0.5 ml saline administered via the tail vein. Nondiabetic animals received an equivalent volume of saline. Following injection, both diabetic and nondiabetic rats were housed in like-pairs and provided with access to normal rat chow (Diet 86 pellets; New Zealand Stock Feeds, Auckland, NZ) and deionized water ad libitum. Blood glucose and body weight were measured at day 3 following STZ/saline injection and then weekly throughout the study. Diabetes was identified by polydipsia, polyuria and hyperglycemia ( $> 11 \text{ mmol}\cdot\text{l}^{-1}$ , Advantage II, Roche Diagnostics, NZ Ltd).

### Experimental procedure.

Six to seven weeks (mean =  $44 \pm 1$  days) after administration of STZ, animals underwent either a control or drug experimental protocol. All animals were fasted overnight prior to surgery but continued to have ad libitum access to deionized water. Induction and maintenance of surgical anesthesia was by 3 - 5% halothane and  $2\text{ l}\cdot\text{min}^{-1}$   $\text{O}_2$ . The femoral artery and vein were cannulated with a solid-state blood pressure

transducer (Mikrotip™ 1.4F, Millar Instruments, Texas, USA) and a saline filled PE 50 catheter respectively. The ureters were exposed via a midline abdominal incision, cannulated using polyethylene catheters (external diameter 0.9 mm, internal diameter 0.5 mm) and the wound sutured closed. The trachea was cannulated and the animal ventilated at 70-80 breaths.min<sup>-1</sup> with air supplemented with O<sub>2</sub> (Pressure Controlled Ventilator, Kent Scientific, Connecticut, USA). The respiratory rate and end-tidal pressure (10-15 cmH<sub>2</sub>O) were adjusted to maintain end-tidal CO<sub>2</sub> at 35-40 mmHg (SC-300 CO<sub>2</sub> Monitor, Pryon Corporation, Wisconsin, USA). Body temperature was maintained at 37°C throughout surgery and the experiment by a heating pad. Estimated fluid loss was replaced with intravenous administration of 154 mmol.l<sup>-1</sup> NaCl solution at a rate of 5 ml.kg<sup>-1</sup>.h<sup>-1</sup>.

Following surgery and a 20 min stabilization period, the experimental protocol was started. Trientine was administered intravenously over 60 s in hourly doses of increasing strength (0.1, 1.0, 10 and 100 mg.kg<sup>-1</sup> in 75 µl saline followed by 125 µl saline flush). Control animals received an equivalent volume of saline. Urine was collected in 15 min aliquots throughout the experiment in pre-weighed polyethylene eppendorf tubes. At the end of the experiment a terminal blood sample was taken by cardiac puncture and the separated serum stored at -80°C until future analysis. Hearts were removed through a rapid mid-sternal thoracotomy and processed as described below.

#### *Data acquisition.*

Mean arterial pressure (MAP), heart rate (HR, derived from the MAP waveform) oxygen saturation (Nonin 8600V Pulse Oximeter, Nonin Medical Inc., Minnesota, USA) and core body temperature, were all continuously monitored throughout the experiment using a PowerLab/16s data acquisition module (AD Instruments, Australia). Calibrated signals were displayed on screen and saved to disc as 2 s averages of each variable.

#### *Urine and tissue analysis.*

Instrumentation: A Perkin Elmer (PE) Model 3100 Atomic Absorption Spectrophotometer equipped with a PE HGA-600 Graphite Furnace and PE AS-60



Furnace Autosampler was used for Cu and Fe determinations in urine. Deuterium background correction was employed. A Cu or Fe hollow-cathode lamp (Perkin Elmer Corporation) was used and operated at either 10 W (Cu) or 15 W (Fe). The 324.8 nm atomic line was used for Cu and the 248.3 nm atomic line for Fe. The slit width for both Cu and Fe was 0.7 nm. Pyrolytically coated graphite tubes were used for all analyses. The injection volume was 20  $\mu\text{L}$ . A typical graphite furnace temperature program is shown below (table 1).

**Table 1: GF-AAS temperature program**

<i>Procedure</i>	<i>Temp / °C</i>	<i>Ramp / s</i>	<i>Hold / s</i>	<i>Int. Flow / mL min<sup>-1</sup></i>
Drying	90	1	5	300
	120	60	5	300
Pre-treatment	1250*	20	10	300
	20	1	10	300
Atomization – Cu / Fe	2300 / 2500	1	8	0
Post-treatment	2600	1	5	300

- A pre-treatment temperature of 1050 °C was used for tissue digest analyses

Cu, Fe and Zn in tissue digests were also determined at Hill Laboratories (Hamilton, New Zealand) using either a PE Sciex Elan-6000 or PE Sciex Elan-6100 DRC ICP-MS. The operating parameters are summarised in the table below (table 2).

**Table 2 : Instrumental operating parameters for ICP-MS**

<i>Parameter</i>	<i>Value</i>
Inductively coupled plasma	
Radiofrequency power	1500 W
Argon plasma gas flow rate	15 l.min <sup>-1</sup>
Argon auxiliary gas flow rate	1.2 l.min <sup>-1</sup>
Argon nebuliser gas flow rate	0.89 l.min <sup>-1</sup>

**Interface**

Sampler cone and orifice diameter	Ni / 1.1 mm
Skimmer cone and orifice diameter	Ni / 0.9 mm

**Data acquisition parameters**

Scanning mode	Peak hopping
Dwell time	30 ms (Cu, Zn) / 100 ms (Fe)
Sweeps / replicate	20
Replicates	3
Sample uptake rate	1 ml.min <sup>-1</sup>

**Reagents:** All reagents used were of the highest purity available and at least of analytical grade. GF-AAS standard working solutions of Cu and Fe were prepared by stepwise dilution of 1000 mg.l<sup>-1</sup> (Spectrosol standard solutions; BDH). Water was purified by a Millipore Milli-Q ultra-pure water system to a resistivity of 18 MΩ. Standard Reference Material 1577b Bovine Liver was obtained from the National Institute of Standards and Technology and used to evaluate the efficiency of tissue digestion. The results obtained are reported below (table 3).

**Table 3 : GF-AAS and ICP-MS results for NIST SRM 1577b bovine liver\***

<i>Element</i>	<i>Certified value</i>	<i>GF-AAS</i>	<i>ICP-MS</i>
Cu	160 ± 8	142 ± 12	164 ± 12
Fe	184 ± 15	182 ± 21	166 ± 14
Zn	127 ± 16	—	155 ± 42

\* Measured in µg.g<sup>-1</sup> of dry matter.

***Sample pretreatment:***

**Urine:** Urine was collected in pre-weighed 1.5 ml micro test tubes (eppendorf). After reweighing, the urine specimens were centrifuged and the supernatant diluted 25:1 with 0.02 M 69 % Aristar grade HNO<sub>3</sub>. The sample was stored at 4 °C prior to GF-AAS

analysis. If it was necessary to store a sample for a period in excess of 2 weeks, it was frozen and kept at  $-20^{\circ}\text{C}$ .

Heart: Following removal from the animal, the heart was cleaned of excess tissue, rinsed in buffer to remove excess blood, blotted dry and a wet ventricular weight recorded. Using titanium instruments a segment of left ventricular muscle was dissected and placed in a pre-weighed 5.0 ml polystyrene tube. The sample was freeze-dried overnight to constant weight before 0.45 ml of 69% Aristar grade  $\text{HNO}_3$  was added. The sample tube was heated in a water bath at  $65^{\circ}\text{C}$  for 60 minutes. The sample was brought to 4.5 ml with Milli-Q  $\text{H}_2\text{O}$ . The resulting solution was diluted 2:1 in order to reduce the  $\text{HNO}_3$  concentration below the maximum permitted for ICP-MS analysis. The remaining left ventricular tissue was stored in 10% formalin and later processed for transmission electron microscopic examination and histochemical analysis.

Serum: Terminal blood samples were centrifuged and serum treated and stored as per urine until analysis. From the trace metal content of serum from the terminal blood sample and urine collected over the final hour of the experiment, renal clearance was calculated using the following equation:

$$\text{renal clearance of trace metal} = \frac{\text{concentration of metal in urine } (\mu\text{g. } \mu\text{l}^{-1}) * \text{rate of urine flow } (\mu\text{l.min}^{-1})}{\text{concentration of metal in serum } (\mu\text{g. } \mu\text{l}^{-1})}$$

### ***Statistical analysis.***

All values are expressed as mean  $\pm$  SEM and  $P$  values  $< 0.05$  were considered statistically significant. Student's unpaired  $t$ -test was initially used to test for weight and glucose differences between the diabetic and control groups. For comparison of responses during drug exposure, statistical analyses were performed using analysis of variance (Statistica for Windows v.6.1, SAS Institute Inc., California, USA). Subsequent statistical analysis was performed using a mixed model repeated measures ANOVA design (see: Figure 35 and Table 7 below).

## RESULTS

**Table 4 : Blood glucose, body weight and food consumption in diabetic versus nondiabetic animals.**

Diabetic animals  $n = 14$ , nondiabetic animals  $n = 14$ . Values shown as mean  $\pm$  SEM. Asterisk indicates a significant difference ( $P < 0.05$ ).

	Diabetic	Nondiabetic
Body weight prior to STZ/saline	$303 \pm 3$ g	$303 \pm 3$ g
Blood glucose 3 days following STZ/saline	$*25 \pm 2$ mmol.l <sup>-1</sup>	$5 \pm 0.2$ mmol.l <sup>-1</sup>
Daily food consumption	$*58 \pm 1$ g	$28 \pm 1$ g
Blood glucose on experimental day	$*24 \pm 1$ mmol.l <sup>-1</sup>	$5 \pm 0.2$ mmol.l <sup>-1</sup>
Body weight on experimental day	$*264 \pm 7$ g	$434 \pm 9$ g

### *Effects of STZ on blood glucose and body weight (Table 4)*

Blood glucose increased to  $25 \pm 2 \text{ mmol.l}^{-1}$  three days following STZ injection. Despite a greater daily food intake, diabetic animals lost weight whilst nondiabetic animals continued to gain weight during the 44 days following STZ/saline injection. On the day of the experiment blood glucose levels were  $24 \pm 1$  and  $5 \pm 0 \text{ mmol.l}^{-1}$  and body weight  $264 \pm 7 \text{ g}$  and  $434 \pm 9 \text{ g}$  for diabetic and nondiabetic animals respectively.

### *Cardiovascular variables during infusion*

Baseline levels of MAP during the control period prior to infusion were not significantly different between nondiabetic and diabetic animals ( $99 \pm 4 \text{ mmHg}$ ). HR was significantly lower in diabetic than nondiabetic animals ( $287 \pm 11$  and  $364 \pm 9 \text{ bpm}$  respectively,  $P < 0.001$ ). Infusion of trientine or saline had no effect on these variables except at the highest dose where MAP decreased by a maximum of  $19 \pm 4 \text{ mmHg}$  for the 2 min following administration and returned to pre-dose levels within 10 min. Body temperature and oxygen saturation remained stable in all animals throughout the experiment.

### *Urine Excretion*

Diabetic animals consistently excreted significantly more urine than nondiabetic animals except in response to the highest dose of drug ( $100 \text{ mg.kg}^{-1}$ ) or equivalent volume of saline (Fig. 24). Administration of the  $100 \text{ mg.kg}^{-1}$  dose of trientine also increased urine excretion in nondiabetic animals to greater than that of nondiabetic animals receiving the equivalent volume of saline (Fig. 25). This effect was not seen in diabetic animals.

### *Urinary excretion of Cu and Fe*

Analysis of the dose response curves shows that, at all doses, diabetic and nondiabetic animals receiving drug excreted more Cu than animals receiving an equivalent volume of saline (Fig. 26). To provide some correction for the effects of lesser total body growth of the diabetic animals, and thus to allow more appropriate comparison

between diabetic and nondiabetic animals, excretion rates of trace elements were also calculated per gram of body weight. Figure 27 shows that diabetic animals had significantly greater copper excretion per gram of body weight in response to each dose of drug than did nondiabetic animals. The same pattern was seen in response to saline, however the effect was not always significant.

Total copper excreted over the entire duration of the experiment was significantly increased in both nondiabetic and diabetic animals administered trientine compared with their respective saline controls (Fig. 28). Diabetic animals receiving drug also excreted more total copper per gram of body weight than nondiabetic animals receiving drug. A similar, but not significant trend was seen in response to saline administration (Fig. 29).

In comparison, iron excretion in both diabetic and nondiabetic animals receiving trientine was not greater than animals receiving an equivalent volume of saline (Fig. 30). Analysis per gram of body weight shows diabetic animals receiving saline excrete significantly more iron than nondiabetic animals, however this trend was not evident between diabetic and nondiabetic animals receiving trientine (Fig. 31). Total iron excretion in both diabetic and nondiabetic animals receiving drug was not different from animals receiving saline (Fig 32). In agreement with analysis of dose response curves, total iron excretion per gram of body weight was significantly greater in diabetic animals receiving saline than nondiabetic animals but this difference was not seen in response to trientine (Fig 33).

#### *Serum content and renal clearance of Cu and Fe (Table 5)*

While there was no significant difference in serum copper content, there was a significant increase in renal clearance of copper in diabetic animals receiving drug compared with diabetic animals receiving saline. The same pattern was seen in nondiabetic animals, although the trend was not statistically significant ( $P = 0.056$ ). There was no effect of drug or state (diabetic versus nondiabetic) on serum content or renal clearance of iron.

**Table 5. Serum content and renal clearance of Cu and Fe in diabetic and nondiabetic animals receiving drug or saline.**

	<b>Diabetic</b>		<b>Nondiabetic</b>	
	<i>trientine</i> <i>n</i> = 6	<i>Saline</i> <i>n</i> = 7	<i>trientine</i> <i>n</i> = 4	<i>Saline</i> <i>n</i> = 7
Serum Cu ( $\mu\text{g} \cdot \mu\text{l}^{-1} \times 10^{-4}$ )	$7.56 \pm 0.06$	$9.07 \pm 1.74$	$7.11 \pm 0.41$	$7.56 \pm 0.62$
Serum Fe ( $\mu\text{g} \cdot \mu\text{l}^{-1} \times 10^{-4}$ )	$35.7 \pm 7.98$	$63.2 \pm 16.4$	$33.6 \pm 1.62$	$31.4 \pm 8.17$
Renal clearance Cu ( $\mu\text{l} \cdot \text{min}^{-1}$ )	* $28.5 \pm 4.8$	$1.66 \pm 0.82$	$5.8 \pm 0.28$	$19.9 \pm 6.4$
Renal clearance Fe ( $\mu\text{l} \cdot \text{min}^{-1}$ )	$0.25 \pm 0.07$	$0.38 \pm 0.15$	$0.46 \pm 0.22$	$0.11 \pm 0.03$

Values shown as mean  $\pm$  SEM. Asterisk indicates a significant difference ( $P < 0.05$ ) between diabetic animals receiving trientine and diabetic animals receiving an equivalent volume of saline.

***Metal content of cardiac tissue (Table 6)***

Wet heart weights in diabetic animals were significantly less than those in nondiabetic animals while heart/body weight ratios were increased. In some animals cardiac tissue was also analysed for Cu and Fe content. There was no significant difference in content of either metal between diabetic and nondiabetic animals.

**Table 6: Heart weight, heart weight/body weight ratios and trace metal content of heart tissue in diabetic versus nondiabetic animals.**

	Diabetic	Nondiabetic
Wet heart weight	*0.78 ± 0.02 g	1.00 ± 0.02 g
Heart weight/body weight	*2.93 ± 0.05 mg.g <sup>-1</sup>	2.30 ± 0.03 mg.g <sup>-1</sup>
Cu content	26.7 ± 1.4 µg.g <sup>-1</sup> dry tissue	27.9 ± 0.7 µg.g <sup>-1</sup> dry tissue
Fe content	296 ± 15 µg.g <sup>-1</sup> dry tissue	299 ± 9 µg.g <sup>-1</sup> dry tissue

Diabetic animals: n = 5; nondiabetic animals: n = 10. Values shown as mean ± SEM. Asterisk indicates a significant difference ( $P < 0.05$ ).

## **THE EFFICACY OF TRIENTINE TO RESTORE CARDIAC FUNCTION IN STZ DIABETIC RATS**

### **INTRODUCTION**

Increased tissue copper has been implicated in mechanisms leading to diabetic nerve damage. We therefore hypothesized that tissue accumulation of trace metals might play a role in the mechanisms of diabetic damage in other tissues. Evidence from our earlier studies showed that 6 months of treatment with trientine appears to protect the hearts of diabetic Wistar rats from development of cardiac damage (diabetic cardiomyopathy), as judged by histology. However, it was unknown whether this histological improvement translates into an improvement in cardiac function, a finding that would lend further support to use of trientine therapy in clinical applications.

### **AIM**

The aim of this study was to use an isolated-working-heart model to compare cardiac function in trientine-treated STZ diabetic rats with that in untreated STZ diabetic rats and non-diabetic control rats.



## METHOD

### Animals

The animals used in these experiments received care that complied with the "Principles of Laboratory Animal Care" (National Society for Medical Research), and the study was approved by the University of Auckland Animal Ethics Committee.

Male albino Wistar rats weighing 330-430g were assigned to three experimental groups as follows (table 7):

**Table 7: Experimental groups**

Group	Code	N	Treatment
Group A	STZ	8	Diabetes for 13 weeks
Group B	STZ/D6	8	Diabetes for 13 weeks Drug therapy week 7-13
Group C	Sham	9	Non-diabetic controls

STZ = Streptozotocin

D6 = trientine treatment for 6 consecutive weeks

Diabetes was induced by intravenous streptozotocin (STZ; Sigma; St. Louis, MO). All rats were given a short inhalational anaesthetic (Induction: 5% halothane and 2 L/min oxygen, maintained on 2% halothane and 2 L/min oxygen). Those in the two diabetic groups then received a single intravenous dose of STZ (57 mg/kg body weight) in 0.5 ml saline (0.9%) administered via a tail vein. Non-diabetic sham-treated animals received an equivalent volume of saline. Diabetic and non-diabetic rats were housed in like-pairs and provided with free access to normal rat chow (Diet 86 pellets; New Zealand Stock Feeds, Auckland, NZ) and deionized water *ad libitum*. Animals were housed at 21 degrees and 60% humidity in standard rat cages with a sawdust floor that was changed daily.

Blood glucose was measured in tail-tip capillary blood samples (Advantage II, Roche Diagnostics, NZ Ltd). Sampling was performed on all groups at the same time of the day. Blood glucose and body weight were measured on day 3 following STZ/saline injection and then weekly throughout the study. Diabetes was confirmed by presence of polydipsia, polyuria and hyperglycemia ( $>11 \text{ mmol.L}^{-1}$ ).

In the drug treated diabetic group, trientine was prepared in the drinking water for each cage to a concentration of 50 mg/L. Animals consumed about 260 ml water per day once diabetes was established, to yield a total drug dose per day of 13.3 mg/L. The drug-containing drinking water was administered continuously from week 7 until the animal was sacrificed at week 13. At week 7 animals are expected to have established cardiomyopathy, as shown by our preliminary studies and confirmed in the literature [Rodrigues, 1986 #98].

On the last day of the experiment, animals were anesthetized (5% halothane and 2 L.min<sup>-1</sup> O<sub>2</sub>), and heparin (500 IU.kg<sup>-1</sup>) (Weddel Pharmaceutical Ltd., London) administered intravenously via tail vein. A 2 ml blood sample was then taken from the inferior vena cava and the heart was then rapidly excised and immersed in ice-cold Krebs-Henseleit bicarbonate buffer to arrest contractile activity. Hearts were then placed in the isolated perfused working heart apparatus.

### Perfusion

The aortic root of the heart was immediately ligated to the aortic cannula. Retrograde (Langendorff) perfusion at a hydrostatic pressure of 100 cm H<sub>2</sub>O and at 37°C was established and continued for 5 min while cannulation of the left atrium via the pulmonary vein was completed. The non-working (Langendorff) preparation was then converted to the working heart model by switching the supply of perfusate buffer from the aorta to the left atrium at a filling pressure of 10 cm H<sub>2</sub>O. The left ventricle spontaneously ejected into the aortic cannula against a hydrostatic pressure (afterload) of 76 cmH<sub>2</sub>O (55.9 mmHg). The perfusion solution was Krebs-Henseleit bicarbonate buffer (mM: KCl 4.7, CaCl<sub>2</sub> 2.3, KH<sub>2</sub>PO<sub>4</sub> 1.2, MgSO<sub>4</sub> 1.2, NaCl 118, and NaHCO<sub>3</sub> 25), pH 7.4 containing 11 mM glucose and it was continuously gassed with 95% O<sub>2</sub>:5% CO<sub>2</sub>. Buffer was continuously filtered in-line (initial 8 cmc, following 0.4 cmc cellulose acetate filters; Sartorius, Germany). The temperature of the entire perfusion apparatus was maintained by water jackets; buffer temperature was continuously monitored and adjusted to maintain hearts at 37°C throughout perfusion.

### **Pressure monitoring and pacing**

A modified 24g plastic cannula (Becton Dickson, Utah, USA) was inserted into the left ventricle via the apex of the heart using the normal introducer-needle. This was attached to a SP844 piezo-electric pressure transducer (AD Instruments) to continuously monitor left ventricular pressure. Aortic pressure was continuously monitored through the side arm of the aortic cannula with a pressure transducer (Statham Model P23XL, Gould Inc., CA, USA). The heart was paced (Digitimer Ltd, Heredfordshire, England) at a rate of 300 bpm by means of electrodes attached to the aortic and pulmonary vein cannulae using supra-threshold voltages with pulses of 5-ms duration from the square wave generator.

### **Aortic flow measurements**

Aortic flow was recorded by an in-line flow meter (Transonic T206, Ithaca, NY, USA) and coronary flow was measured by timed 30 s collection of the coronary vein effluent at each time point step of the protocol.

### **Working heart apparatus**

This working heart apparatus was a variant of that originally described by Neely JR. Liebermeister H. Battersby EJ. Morgan HE. Effect of pressure development on oxygen consumption by isolated rat heart. *American Journal of Physiology*. 212(4):804-14, 1967 Apr. Neely JR. Liebermeister H. Battersby EJ. Morgan HE. Effect of pressure development on oxygen consumption by isolated rat heart. *American Journal of Physiology*. 212(4):804-14, 1967 Apr. Neely JR. Liebermeister H. Battersby EJ. Morgan HE. Effect of pressure development on oxygen consumption by isolated rat heart. *American Journal of Physiology*. 212(4):804-14, 1967 Apr.. Our modified apparatus allowed measurements of cardiac function at different preload pressures (Figure 23A and Figure 23B). This was achieved by constructing the apparatus so that the inflow height of the buffer coming to the heart could be altered through a series of graduated steps in a reproducible manner. As in the case of the afterload, the outflow tubing from the aorta

could be increased in height to provide a series of defined afterload pressures; these have been converted to mmHg for presentation in the results.

### **Data collection**

All data from the pressure transducers and flow probe were collected (Powerlab 16s data acquisition machine; AD Instruments, Australia). The data processing functions of this device were used to calculate the first derivative of the two pressure waves (ventricular and aortic). The final cardiac function data reported comprised:

Cardiac output\*; aortic flow; coronary flow; mean left ventricular pressure developed (MLVDP); maximum rate of ventricular pressure development ( $+dP/dt$ )\*\*; maximum rate of ventricular pressure relaxation ( $-dP/dt$ )\*\*; maximum rate of aortic pressure development (aortic  $+dP/dt$ ); maximum rate of aortic relaxation (aortic  $-dP/dt$ ).

[\*Cardiac output (CO) is the amount of buffer pumped per unit time by the heart and is comprised of buffer that is pumped out of the aorta as well as the buffer pumped into the coronary vessels. This is an overall indicator of cardiac function.

\*\*  $+dP/dt$  is the rate of change of ventricular (or aortic pressure) and correlates well with the strength of the contraction of the ventricle (contractility). It can be used to compare contractile abilities of different hearts when at the same preload (Textbook of Medical Physiology, Ed. A.Guyton. Saunders company 1986).  $-dP/dt$  is an accepted measurement of the rate of relaxation of the ventricle].

### **Protocol**

The experiment was divided into two parts, the first with fixed afterload and variable preload the second, which immediately followed on from the first, with fixed preload and variable afterload.

#### **I) Fixed Afterload and changing Preload**

After the initial cannulation was completed, the heart was initially allowed to equilibrate for 6 min at 10 cm of water atrial filling pressure and 76 cm water afterload. During this period the left ventricular pressure transducer cannula was inserted and the

pacing unit started. Once the heart was stable, the atrial filling pressure was then reduced to 5 cm H<sub>2</sub>O of water and then progressively increased in steps of 2.5 cm H<sub>2</sub>O over a series of 7 steps to a maximum of 20 cm H<sub>2</sub>O. The preload was kept at each filling pressure for 2 min, during which time the pressure trace could be observed to stabilize and the coronary flow was measured. On completion of the variable preload experiment, the variable afterload experiment was immediately commenced.

## II) Fixed Preload and changing Afterload

During this part of the experiment the filling pressure (preload) was set at 10 cm H<sub>2</sub>O and the afterload was then increased from 76 cm H<sub>2</sub>O (55.9 mmHg) in steps of 8 cm H<sub>2</sub>O (5.88 mmHg); again each step was of 2 min duration. The maximum height (afterload) to which each individual heart was ultimately exposed, was determined either by attainment of the maximal available afterload height of 145 cm H<sub>2</sub>O (106.66 mmHg), or the height at which measured aortic flow became less than 5 ml/min. In the later situation, the heart was considered to have "functionally failed". To ensure that this failure was mechanical and not due to other causes (e.g. ischaemic damage) all hearts were then returned to the initial perfusion conditions (preload 10 cm H<sub>2</sub>O; afterload 75 cm H<sub>2</sub>O) for 4 min to confirm that pump function could be restored.

At the end of this period the hearts were arrested with a retrograde infusion of 0.4 ml of cold KCL (24 mM). The atria and vascular remnants were then excised, the heart blotted dry, and the ventricles incised midway between the apex and atrioventricular sulcus. Measurements of the ventricular wall thickness were then made using a micro-caliper (Absolute Digimatic, Mitutoyo Corp, Japan).

## ANALYSIS

Data from the Powerlab was extracted by averaging 1 min intervals from the stable part of the electronic trace generated from each step in the protocol. The results from each group were then combined and analysed for differences between the groups for the various cardiac function parameters (aortic flow, cardiac flow, MLVDP, LV or aortic +/- dP/dt).

## RESULTS

### Animals

The weights of the animals at the end of the experimental period are shown in Table 8. Because there was a small difference in the initial weights of the animals, a graph of the percentage change in weight for each group has been included (Figure 5B).

**Table 8: Initial and Final Animal weights (mean  $\pm$  SD)**

	Number (n)	Treatment	Initial weight (g)		Final weight (g)	
Group A	9	STZ	361 $\pm$ 12	* * *	221 $\pm$ 27	* * *
Group B	8	STZ/D6	401 $\pm$ 33		290 $\pm$ 56	
Group C	8	Sham	361 $\pm$ 16		574 $\pm$ 50	

\*  $P < 0.01$

### Diabetic status

Blood glucose values for the three groups of rats are presented in Figure 6. Generally, the presence of diabetes was confirmed established within 3-5 days following the STZ injection. The Sham control group remained normoglycaemic throughout the experiment, and treatment with the drug made no difference to their blood glucose profile ( $p=ns$ ), as expected.

### Heart weights

Final heart weight and ventricular wall thickness measurements are presented in Table 9.

**Table 9: Final heart weights (g) and per g of animal body Weight (BW) (mean  $\pm$  SD)**

Group	Heart weight (g)	Heart weight (g) /BW (g)	Left Ventricular wall thickness (mm)	Left Ventricular wall thickness (mm)/BW (g)
Sham	1.58 $\pm$ 0.13 <sup>§</sup>	0.0028 $\pm$ 0.0002 <sup>§</sup>	3.89 $\pm$ 0.38 <sup>§</sup>	0.0068 $\pm$ 0.0009 <sup>§</sup>
STZ/D6	1.18 $\pm$ 0.24	0.0041 $\pm$ 0.0005	3.79 $\pm$ 0.52	0.0127 $\pm$ 0.0027
STZ	1.03 $\pm$ 0.17	0.0047 $\pm$ 0.0004	3.31 $\pm$ 0.39	0.0152 $\pm$ 0.0026

•  $P=0.02$

• § = Highly significant when compared with the other 2 groups

### Part I results

The following graphs of Figures 7 to 14 demonstrate cardiac performance parameters of the animals (STZ diabetic; STZ diabetic +drug; and sham-treated controls) while undergoing increasing atrial filling pressure (5-20 cmH<sub>2</sub>O, preload) with a constant afterload of 75 cm H<sub>2</sub>O.

Cardiac output (Figure 7) is the sum to the aortic flow (Figure 9) and the coronary flow as displayed in Figure 8. Since the control hearts and experimental groups have significantly different final weights, the coronary flow is presented (Figure 8A) as the flow normalized to heart weight [Note that coronary flow is generally proportional to cardiac muscle mass, and therefore to cardiac weight].

The mean left ventricular developed pressure (MLVDP) is summarized in Figure 10. The first derivative of the pressure curve gives the rate of change in pressure development in the ventricle with each cardiac cycle and the maximum positive rate of change (+dP/dt) value is plotted in Figure 11. The corresponding maximum rate of relaxation (-dP/dt) is in Figure 12. Similar information appears in Figure 13 and Figure 14, in which the maximum positive and negative rates of change in pressure within the aortic outflow tubing are shown.

All results are mean  $\pm$  sem.

Sham (n=9), STZ diabetic (n=8), STZ Diabetic + Drug (D6) (n=8)

# p<0.01 STZ/D6 v STZ

\*p<0.01 STZ/D6 v Sham

### Part II results

A similar set of graphs are presented in Figures 15 to 22 and Figure 34 which demonstrate equivalent functional outcomes, but this time under conditions of constant preload and changing afterload. Results are mean  $\pm$  sem.

Note: In part I of the experiment, all hearts remained functional throughout all the changes in preload. However in this section, the increased work associated with the higher afterloads was used as an additional indicator of cardiac function. The numbers of functionally surviving hearts (n) in each group varies at higher afterload levels. This

attrition reflects functional failure of the heart at the stated level of afterload. (See Table 10 and Figure 34).

Table 10: Cardiac survival at each afterload pressure

Number surviving				Percentage					
Afterload (mmHg)	STZ	STZ/D6	Sham			Afterload (mmHg)	STZ	STZ/D6	Sham
55.9	8	8	9			55.9	100%	100%	100%
61.8	8	8	9			61.8	100%	100%	100%
67.7	8	8	9			67.7	100%	100%	100%
71.4	6	8	9			71.4	75%	100%	100%
77.2	5	8	9			77.2	63%	100%	100%
83.1	4	8	9			83.1	50%	100%	100%
88.3	3	7	9			88.3	38%	88%	100%
94.9	1	6	9			94.9	13%	75%	100%
100.8	0	5	9			100.8	0%	63%	100%
106.7	0	1	9			106.7	0%	13%	100%

## SUMMARY

- Treatment with trientine had no obvious effect on blood glucose concentrations in the two diabetic groups (as expected).
- There was a small but significant improvement in the cardiac weight /body weight ratio in the trientine-treated diabetic group compared to that of the untreated diabetic group.
- When the Preload was increased with the Afterload held constant, cardiac output was restored to Sham values. Both the aortic and absolute coronary flows improved in the drug treated group.
- When the coronary flow was normalized to heart weight, the drug treated group still showed improved flows at lower filling pressures than did the untreated diabetic animals.
- Indicators for ventricular contraction and relaxation were both significantly improved in the drug treated group compared to equivalent values in the untreated



diabetic group. The improvement restored function to such an extent that there was no significant difference between the drug treated and the sham-treated control groups.

- The aortic transducer measures of pressure change also showed improved function in the drug treated group
- When afterload was increased in the presence of constant preload, it was observed that the heart's ability to function at higher afterload was greatly improved in the drug treated diabetic group compared to the untreated diabetic group. When 50% of the untreated hearts had failed, 100% of the drug treated hearts were still functioning.
- Compared to the untreated diabetic hearts, the response of the drug treated diabetic hearts showed significant improvements in several variables: cardiac output, aortic flow, coronary flow, as well as improved ventricular contraction and relaxation indices in both the ventricular and aortic pressure wave profiles.

## CONCLUSION

These preliminary data suggest that treatment of STZ diabetic rats with trientine dramatically improves several measures of cardiac function.

### Additional relevant notes:

Other published studies in Wistar rats have shown that the functional changes of the cardiomyopathy of STZ rats is

- Cardiomyopathy is present after 5-6 weeks following STZ  
*Rodrigues B, Am J Physiol 251 H571-H580 1986*
- Not related to heart size: since small weight matched hearts have same function as larger control hearts (we confirmed this in our pilot study as well)
- Not due to malnutrition effects of low insulin: since calorie deprived rats with hearts of the same weight had the same function as larger control hearts
- Not substrate dependent: addition of extra insulin and increased glucose did not reverse the functional deficit
- Probably not due to the STZ itself: since animals given STZ in this study but that

failed to go on to develop diabetes, did not get a change in heart function

*Penpargkul S et al, Cir Res 4: 911-921 1980*

### **Interim Conclusions:**

Administration of oral Trientine for 6 weeks in Wistar rats with previously established diabetes of 7 weeks duration (a duration known from the literature and our first pilot study, to be associated with significant cardiomyopathy) resulted in a global improvement in cardiac function. This improvement was demonstrated by measures of improved contractile function (LVDP most clearly seen in the afterload experiment  $+dP/dT$ ) and a reduction in ventricular stiffness ( $-dP/dT$ ). These parameters improved in the presence of either increasing preload or after-load protocols.

### **SUMMARY.**

The acute effect of intravenous trientine administration on urinary excretion of copper and iron was studied in anesthetized, diabetic (6 weeks of diabetes, Streptozotocin induced) and nondiabetic rats. Animals were assigned to one of four groups: diabetic + trientine, diabetic + saline, nondiabetic + trientine, nondiabetic + saline. Drug, or an equivalent volume of saline, was administered hourly in doses of increasing strength (0.1, 1.0, 10, 100  $\text{mg.kg}^{-1}$ ) and urine was collected throughout the experiment in 15 min aliquots. A terminal blood sample was taken and cardiac tissue harvested.

Analysis of urine samples showed the following main points:

- At all drug doses, diabetic and nondiabetic animals receiving drug excreted more Cu ( $\mu\text{g}$ ) than animals receiving an equivalent volume of saline.
- When analysed per gram of bodyweight, diabetic animals excreted significantly more copper ( $\mu\text{g.gBW}^{-1}$ ) at each dose of trientine than did nondiabetic animals. The same pattern was seen in response to saline but the effect was not significant at every dose.
- At most doses, in diabetic animals iron excretion ( $\mu\text{g}$ ) was greater in animals administered saline than in those administered drug. In nondiabetic

animals there was no difference between iron excretion in response to saline or trientine administration.

- Analysis per gram of body weight shows no difference between iron excretion in nondiabetic and diabetic animals receiving trientine. Diabetic animals receiving saline excrete more iron per gram of bodyweight than nondiabetic animals receiving saline.

Analysis of heart tissue showed no significant difference in content of either metal between diabetic and nondiabetic animals, nor any effect of drug on cardiac content of iron and copper.

Renal clearance calculations showed a significant increase in clearance of copper in diabetic animals receiving trientine compared with diabetic animals receiving saline. The same trend was seen in nondiabetic animals but the effect was not significant. There was no effect of trientine on renal clearance of iron.

In summary, trientine-treatment effectively increases copper excretion in both diabetic and nondiabetic animals. The excretion of copper in urine following trientine administration, is greater per gram of bodyweight in diabetic than in nondiabetic animals. Iron excretion was not increased by trientine treatment in either diabetic or nondiabetic animals.

### Statistical methods

Data for each dose level were analysed using a mixed linear model (PROC MIXED; SAS, Version 8). The model included diabetes, drug and their interaction as fixed effects, time as a repeated measure, and rats as the subjects in the dataset. Complete independence is assumed across subjects. The full model was fitted to each dataset using a maximum likelihood estimation method (REML) fits mixed linear models (i.e., fixed and random effects models). A mixed model is a generalization of the standard linear model, the generalization being that you can analyse data generated from several sources of variation instead of just one. A level of significance of 0.05 was used for all tests.

## RESULTS

### Copper

Diabetic rats excreted significantly higher levels of copper across all dose levels. Baseline copper excretion was also significantly higher in diabetic rats compared to and prior to drug administration. The drug resulted in a significantly higher excretion of copper compared to saline at all dose levels. There was no difference at baseline levels between the drug and saline groups. The interaction effect for the model was significant at dose levels of  $1.0 \text{ mg.kg}^{-1}$  and above. The presence of a significant interaction term means that the influence of each effect varies with the level of the other effect. Therefore, the outcome of a significant interaction between the diabetes and drug factors in increased copper excretion above the predicted additive effects of these two factors.

### Iron

Diabetic rats in the saline only group excreted significantly higher levels of iron at all dose levels. This resulted in all factors in the model being significant across all dose levels.

### *Statistical analysis using a mixed linear model.*

Data for each dose level were analysed using a mixed linear model (PROC MIXED; SAS, Version 8). The model included *diabetes*, *drug* and their interaction as fixed effects, *time* as a repeated measure, and *rats* as the subjects in the dataset. Complete independence is assumed across subjects. The full model was fitted to each dataset using a maximum likelihood estimation method (REML) fits mixed linear models (i.e., fixed and random effects models). A mixed model is a generalization of the standard linear model, the generalization being that you can analyse data generated from several sources of variation instead of just one. A level of significance of 0.05 was used for all tests.

**Results from application of the above mixed linear model to the experimental analysis (Figure 35).**

Diabetic rats excreted significantly higher levels of copper across all dose levels. Baseline copper excretion was also significantly higher in diabetic rats compared to and prior to drug administration. The drug resulted in a significantly higher excretion of copper compared to saline at all dose levels. There was no difference at baseline levels between the drug and saline groups.

The interaction effect for the model was significant at dose levels of  $1.0 \text{ mg.kg}^{-1}$  and above. The presence of a significant interaction term means that the influence of one effect varies with the level of the other effect. Therefore, the outcome of a significant interaction between the diabetes and drug factors is increased copper excretion above the predicted additive effects of these two factors.

Diabetic rats in the saline only group excreted significantly higher levels of iron at all dose levels. This resulted in all factors in the model being significant across all dose levels.

In the STZ rat model, animals made diabetic for more than 6 weeks show damaged cardiac structure with atrophy and loss of myocytes, expansion of the extracellular space, and increased deposition of extracellular matrix. These appearances are both ameliorated and reversed by chronic oral therapy with trientine dihydrochloride. See, Figures 1A & 1B.

Using the isolated working heart model, cardiac function is severely impaired in STZ diabetic rats compared with non-diabetic animals. Cardiac dysfunction is largely corrected by chronic oral therapy with trientine hydrochloride. See, Figures 2A & 2B.

## **HUMAN STUDIES – Phase II**

Table 11 shows baseline information on 30 patients with long-standing type 2 diabetes, no clinical evidence of coronary artery disease and abnormal diastolic function who participated in a 6-month randomised, double blind, placebo controlled study of chronic oral therapy with trientine dihydrochloride.

**Table 11: Characteristics of Study Participants**

	Placebo	Trientine dihydrochloride
N	15	15
Median age (years)	54 (range 43-64)	52 (range 33-69)
% female	44%	56%
Median duration of diabetes (years)	10 (6-24)	8 (4-15)
Mean body mass index (kg/m <sup>2</sup> )	32 (SD 5)	34 (SD 5)
% hypertensive	64%	80%
% HbA <sub>1c</sub> >8	93%	80%

MRI scans of the heart at baseline and 6-months showed a significant reduction in LV mass and a significant improvement in diastolic function measured as a change in apical rotation (AR) at the end of systole. See, Table 12. These effects indicate improved structure and function in the human heart following 6 months of trientine therapy.

**Table 12 : Phase II: INFO-Cardiac**

MRI Results			
	Placebo (n=15)	GC811007 (n=15)	P
Baseline LVM	202.17	207.45	0.778
Δ LVM 1-6mo	+6.57	-10.49	0.0045
Baseline AR	12.37	12.49	0.931
Δ AR 1-6mo	+0.81	-2.19	0.029

Therefore, an equivalent dose of oral trientine dihydrochloride corrected for weight (15 mg/kg) is effective in both rats and humans.

Compared with non-diabetic animals, STZ diabetic rats show a 2-fold to 10-fold excess of urinary copper excretion following parenteral administration of trientine hydrochloride. Cupuresis is rapid with excess urinary copper excretion manifest within the first 15 minutes of an intravenous bolus injection. Trientine dihydrochloride is

effective by parenteral injection in a 10-fold to 100-fold lower dose than an equivalent fast release oral therapy. See, Figure 3 and our patent application filed simultaneously herewith directed to slow release dosage forms and their use.

#### **DOSING REGIMEN FOR TRIENTINE**

The half life of trientine, indicated for the treatment and reversal of heart failure and coronary heart disease, is relatively short – being approximately 2 hours. To maintain optimal blood levels, either multiple dose regimen, or a controlled release preparation requiring fewer doses per day is required.

With reference to Figures 36 and 37 there is shown the plasma concentration – time profiles of trientine after oral administration. The plasma concentration was determined using the process as defined in Miyazaki, K., et al., Determination of trientine in plasma of patients with high-performance liquid chromatography. Chem Pharm Bull, 1990. 38:p. 1035-38.

Ideally trientine should be taken in addition to current therapies, at a maximum tolerated dose, utilizing a dose regimen which fits its pharmacokinetic profile. Patients with heart failure and/or coronary artery disease are frequently on multiple drug regimens. Therefore, a controlled release preparation requiring fewer doses per day is preferred. The proof of principle Phase 2 study has shown positive results. However, the dosage regimen was sub-optimal when compared with its pharmacokinetic profile and the study does not assure the efficacy of the drug which would be required in pivotal trials by regulatory authorities.

The dosage unit, if oral, to extract greater benefit from the active ingredient taken orally preferably delivers not more than 10% trientine dihydrochloride in about 5 hours at an acid pH of about <4.5 and delivers greater than 50% of trientine dihydrochloride in 12 hrs at a pH of about <6.5 in a controlled manner during *in vivo* and *in vitro* dissolution. See our application filed simultaneously herewith directed to such oral formulations in a sustained release form.

We propose as a consequence of the studies undertaken, that equate human copper values depletion against those of the STZ rat, a dosage form each with less than 250 mg of trientine dihydrochloride (or other salt of trientine when expressed as the

dihydrochloride) which will perform sufficiently as shown by the Figure 3 studies reliant on a dose peak much lower than that delivered orally with otherwise equivalent 300 mg oral dosage forms for the treatment of Wilson's disease.

As shown in Figures 3 and 27, in particular, trientine dihydrochloride is effective at removing Cu from diabetic rats at doses lower than have been previously shown to be effective. In particular these data show that it may be effective at doses lower than the (e.g.) 1.2 g/d shown to be effective in rat and man heart disease. It may be effective at doses of  $1/10$ ,  $1/100$  and even  $1/1000$  of those we have already employed. e.g. at 120 mg/d, 12 mg/d or even 1.2 mg/d. This could be given as a bolus dose, but would preferably be delivered in a Modified Release Dosage form, or Extended Release, Delayed Release, slow release or Repeat Action Dosage form.

The evidence we obtained from the ST2-rat experiments showed that the drug is effective when administered in drinking water, a route that creates continuous blood levels of drug

Therefore, administration by dosage form similarly capable of maintaining appropriate blood levels of drug, such as a modified release dosage form, an extended release dosage form, a delayed release dosage form, or a repeat action dosage form, will be particularly preferred.

Envisaged are SYPRINE® capsule forms having less than 250mg trientine dihydrochloride per capsule or tablets or capsules of any suitable form.



DATED THIS 20th DAY OF August 2002  
AJ PARK  
PER *Shigefusa*  
AGENTS FOR THE APPLICANT



# Confocal microscope images of Rat left ventricle

Stain: Phalloidin (f-actin) and Lewis ( $\beta_1$ -integrin)

13 wk Sham

13 wk STZ

13 wk STZ / 7 wk Drug

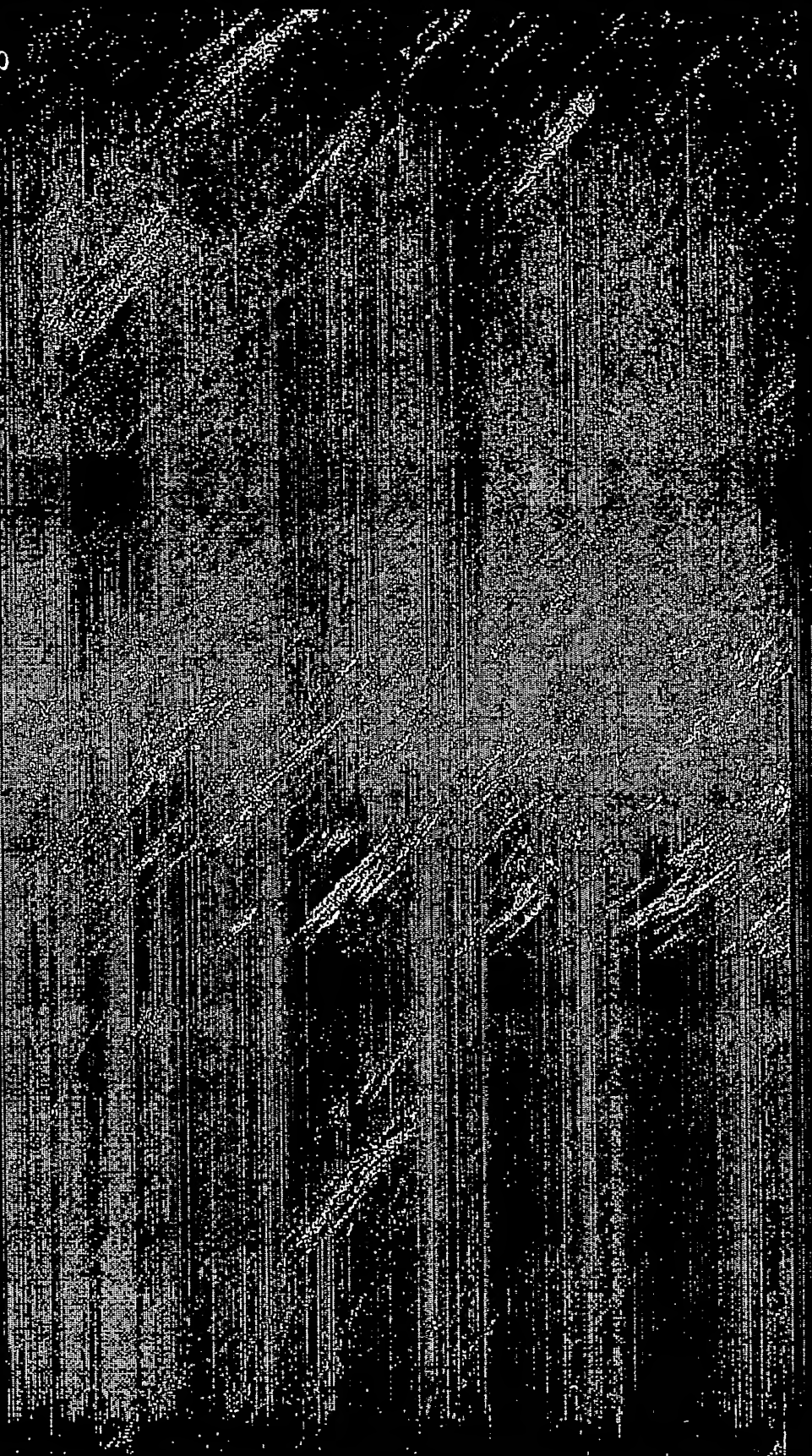


Figure 1A

630 x magnification

# Confocal microscope images of Rat left ventricle

Stain: Phalloidin (f-actin) and Lewis ( $\beta_1$ -integrin)

13 wk Sham

13 wk STZ

13 wk STZ / 7 wk Drug

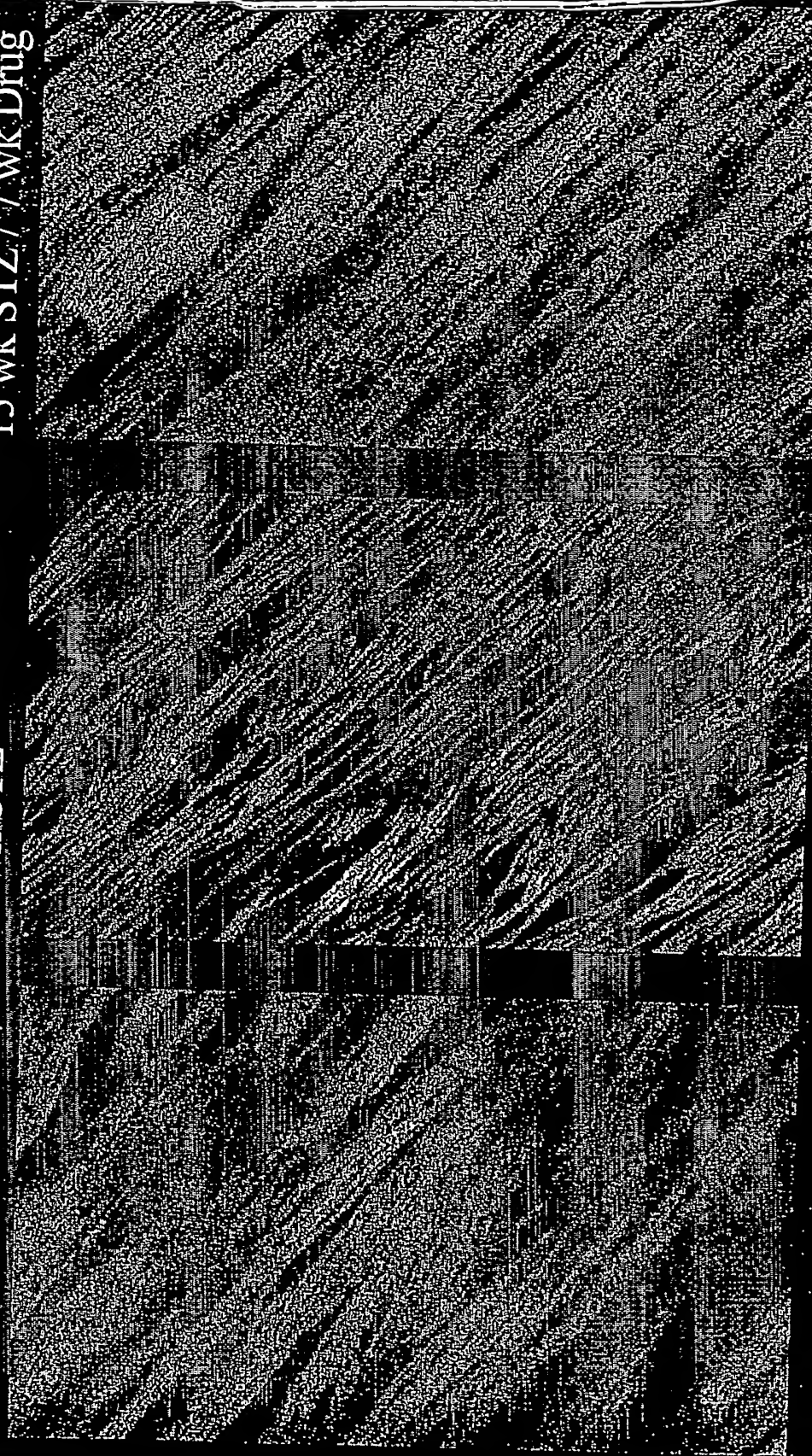
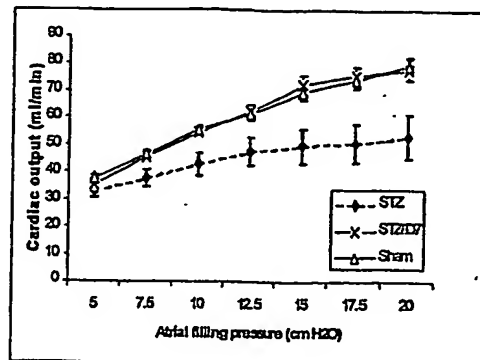


Figure 1B

630 x magnification

## Trientine Restores Normal Heart Function



Cardiac output in response to increasing preload with GC811007 treatment from weeks 7-13

STZ/D7 v STZ =  $p < 0.03$ ; STZ/D7 v Sham = ns; STZ v Sham = all  $p < 0.05$

FIGURE 2A

## Functional Survival of Working Hearts

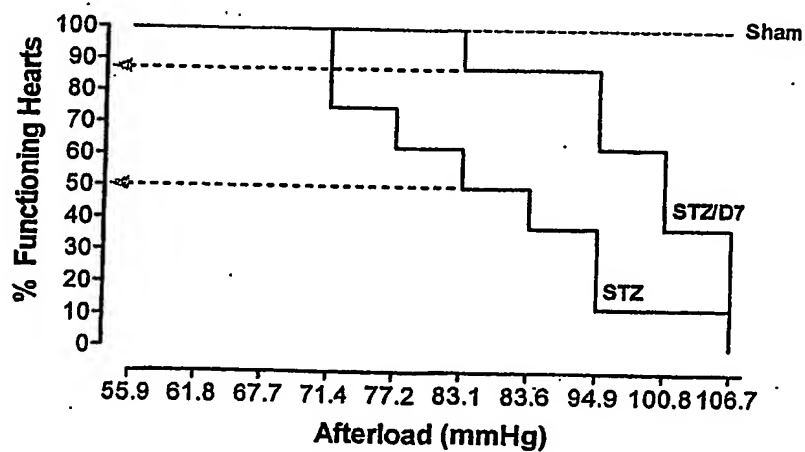
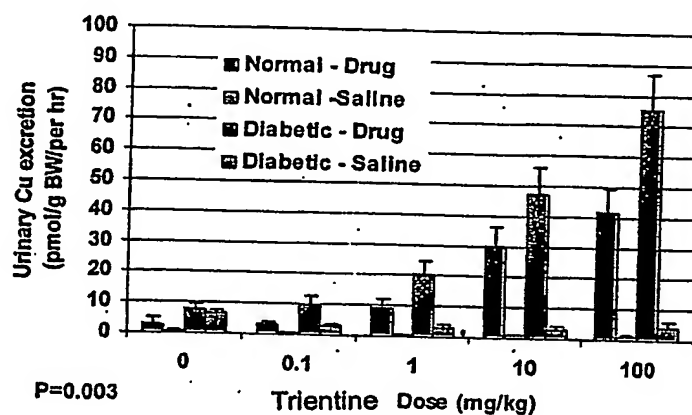


FIGURE 2B

## Trientine Modifies Copper Excretion



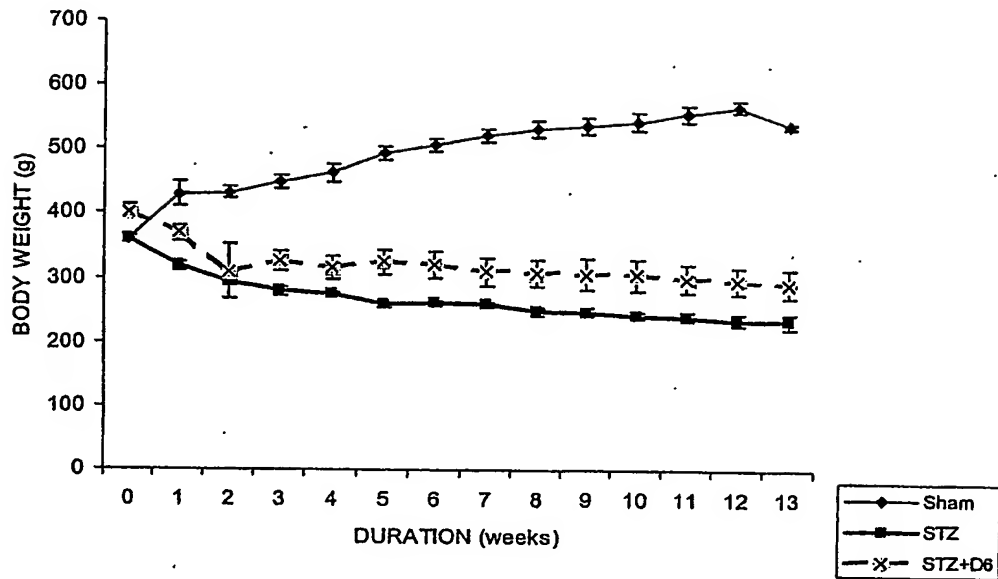
No effect on iron excretion

Indicate where human dose is on x axis

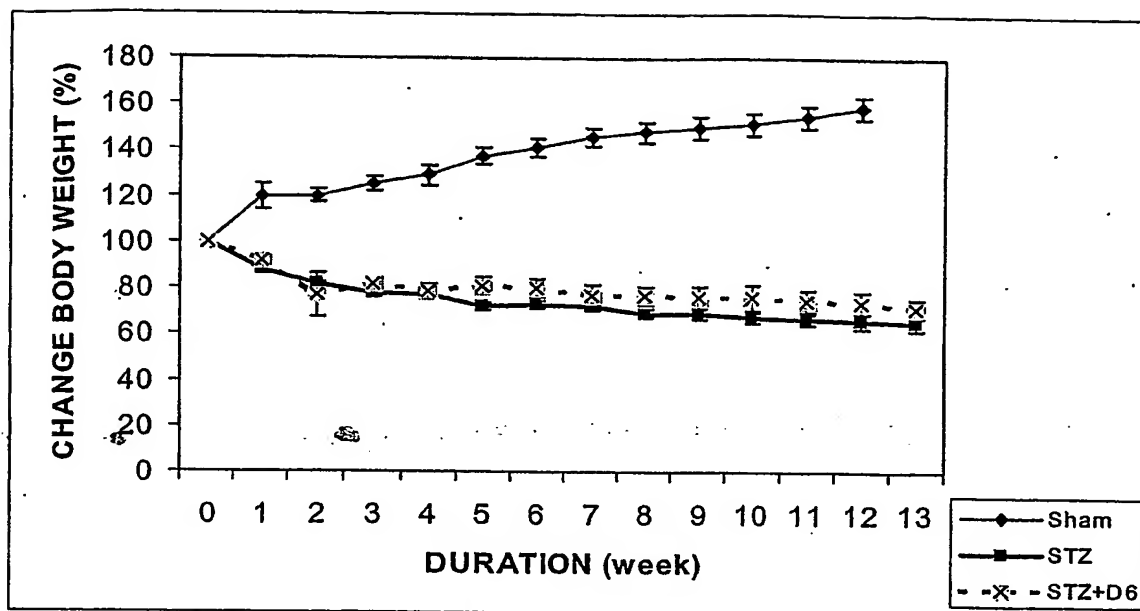
FIGURE 3

4

Figure Absolute Weight Change with time

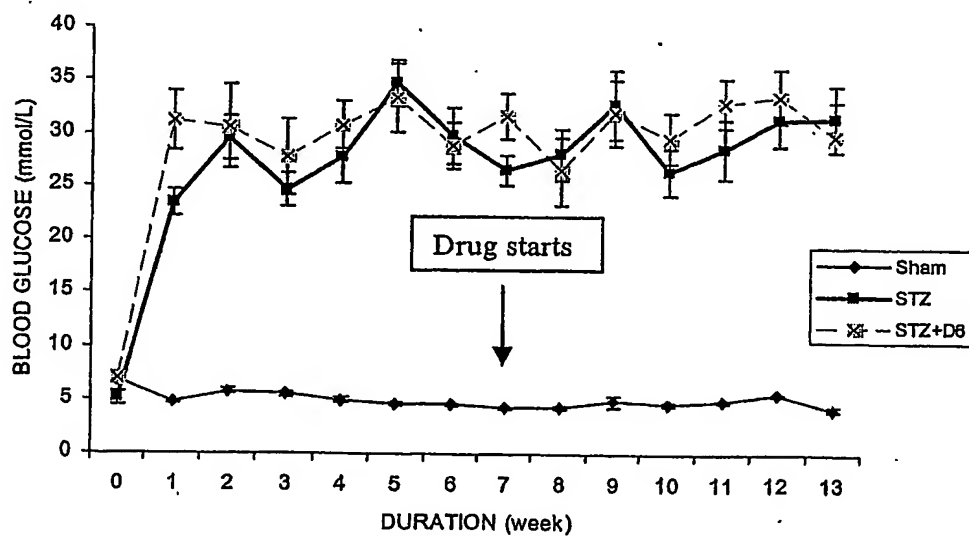


**Figure 5 Percentage change in weight over time**

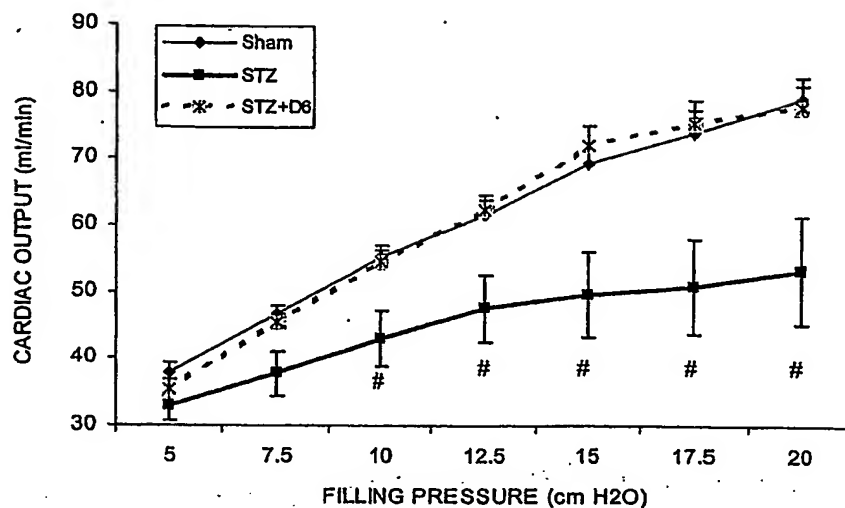


**Figure 6 Blood Glucose change over time**

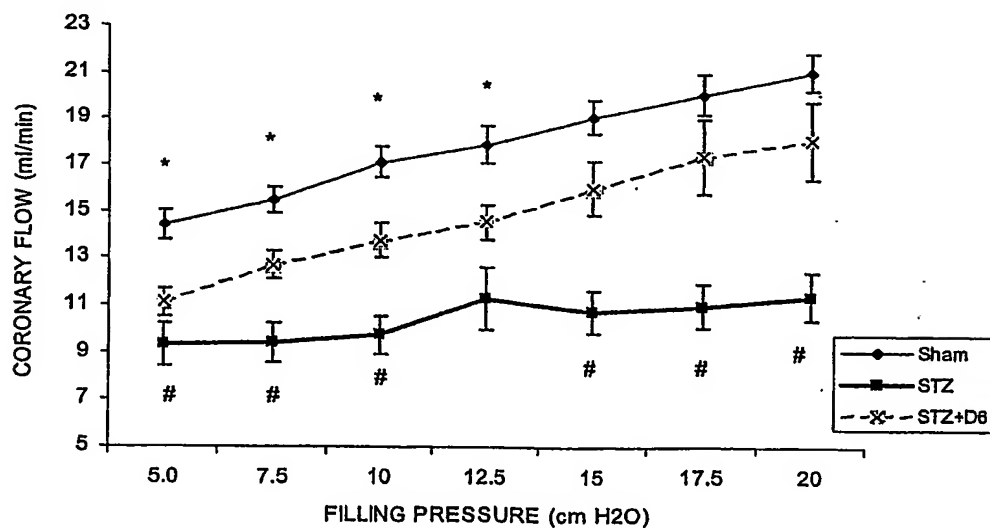
(Weekly glucose measurements)



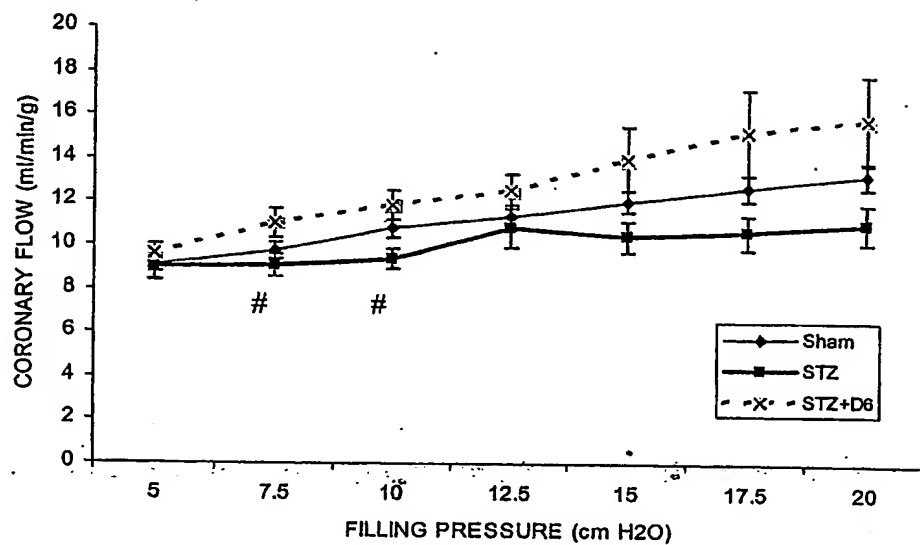
**Figure 7 Cardiac output in response to increasing preload**



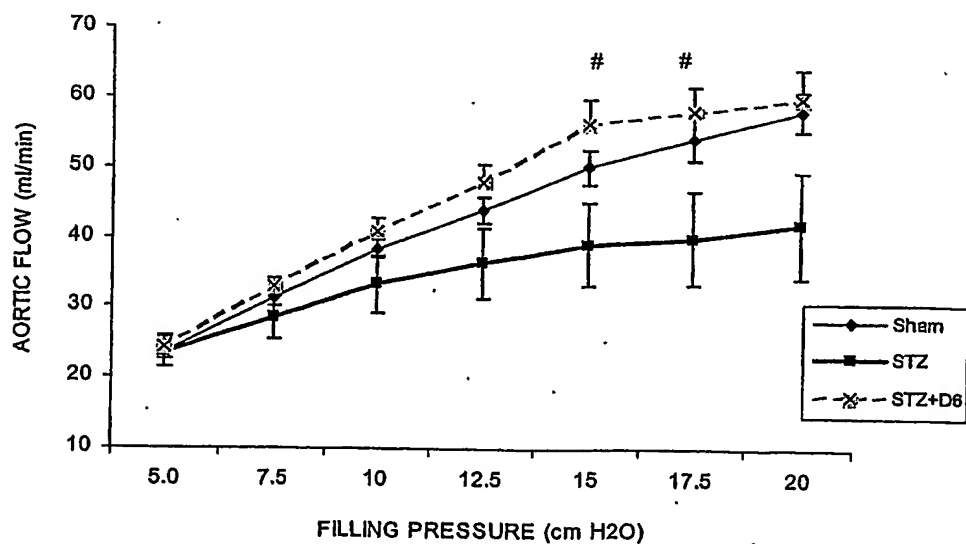
**Figure 8. Absolute coronary flow in response to increasing preload**



**Figure 8A Coronary flow normalized to final cardiac weight**

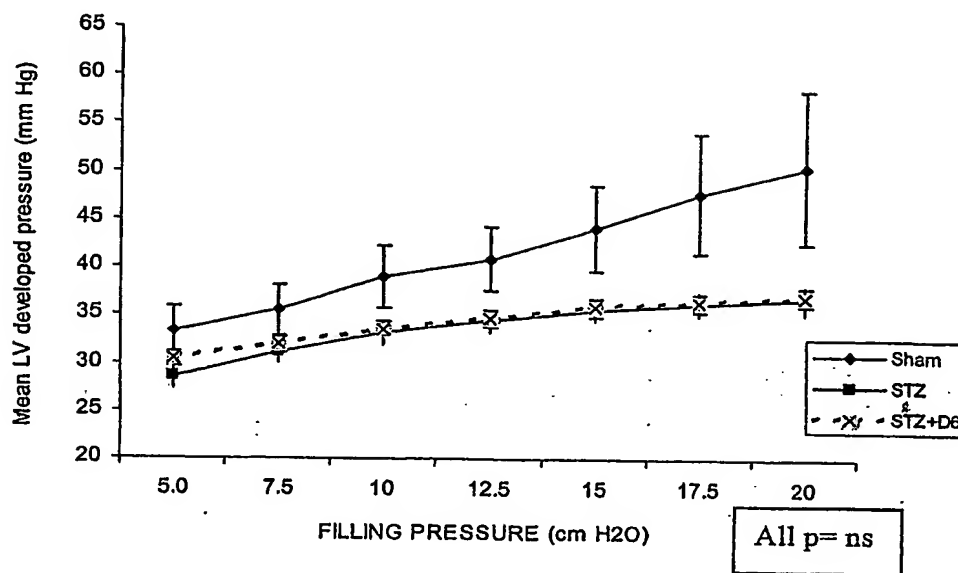


**Figure 9 Aortic flow with increasing preload**

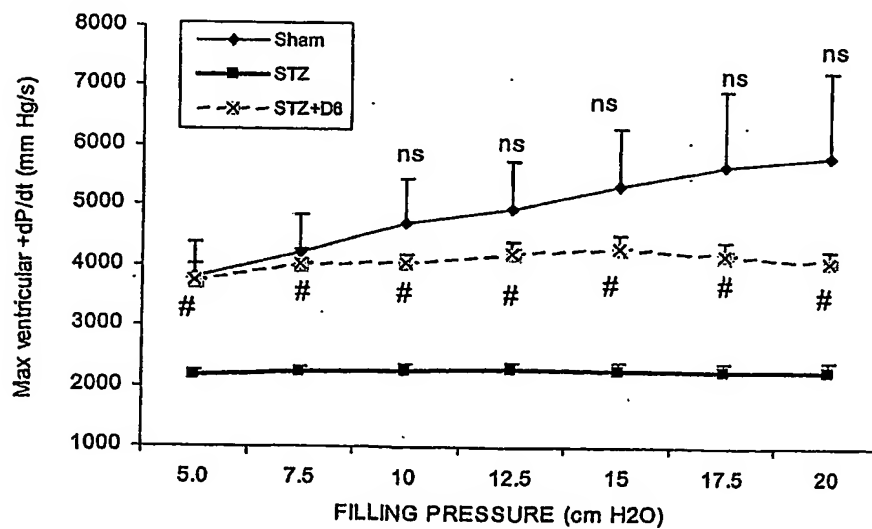




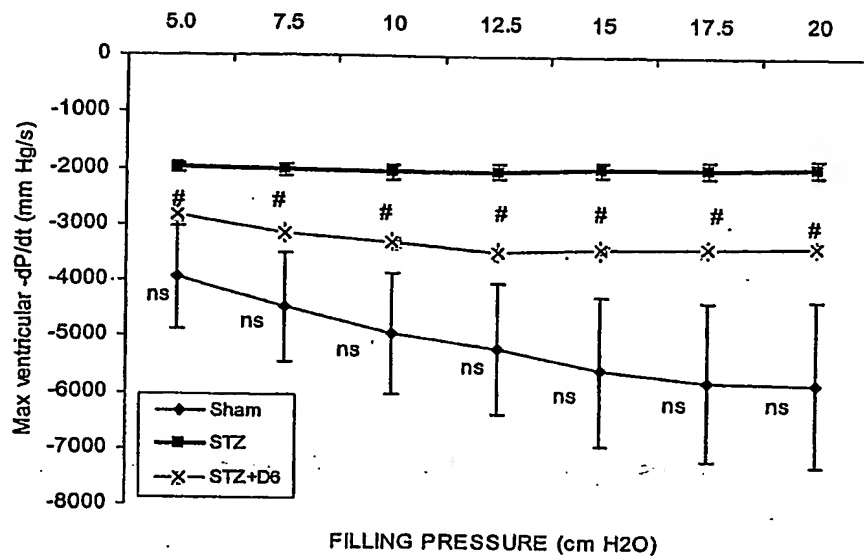
**Figure 10 Mean left ventricular developed pressure (MLVDP) in response to increasing preload**



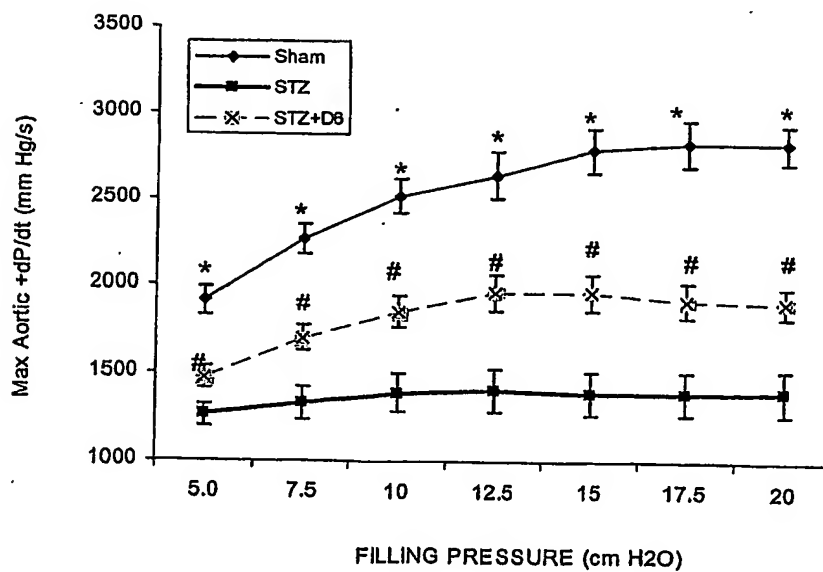
**Figure 11 Maximal rate of positive change in ventricular pressure (contraction) in response to increasing preload**



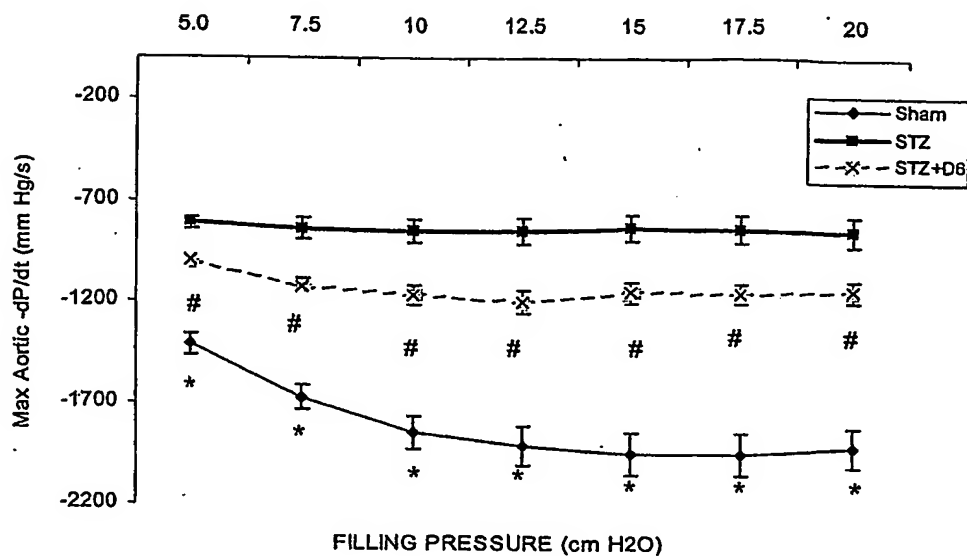
**Figure 12 Maximal rate of decrease in ventricular pressure (relaxation) in response to increasing preload**



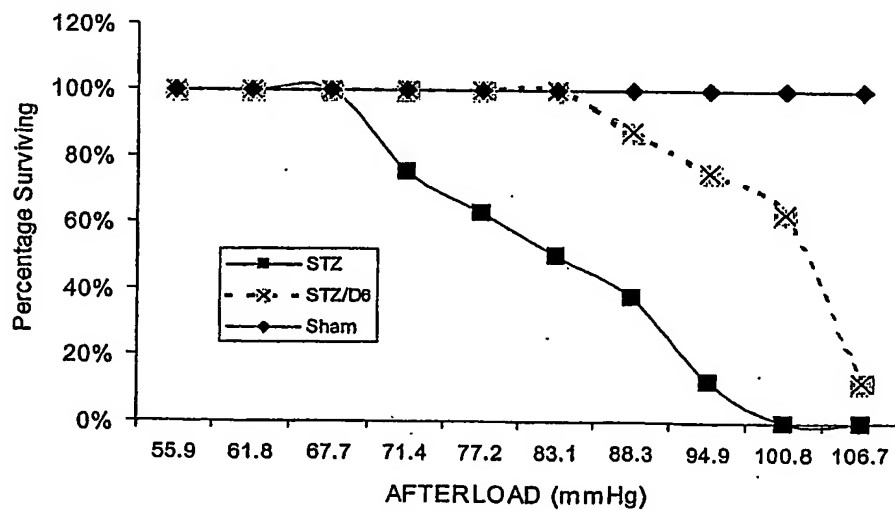
**Figure 13 Maximal rate of positive change in aortic pressure in response to increasing preload**



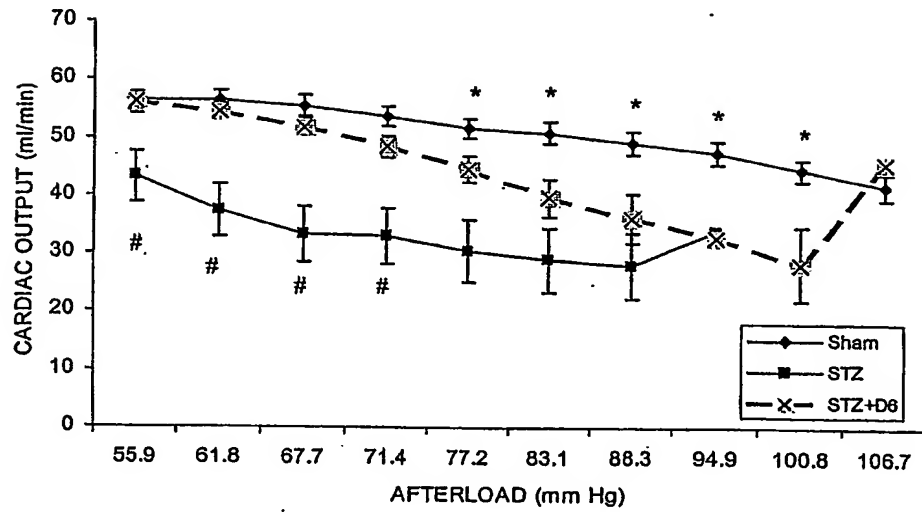
**Figure 14 Maximal rate of decrease in aortic pressure in response to increasing preload**



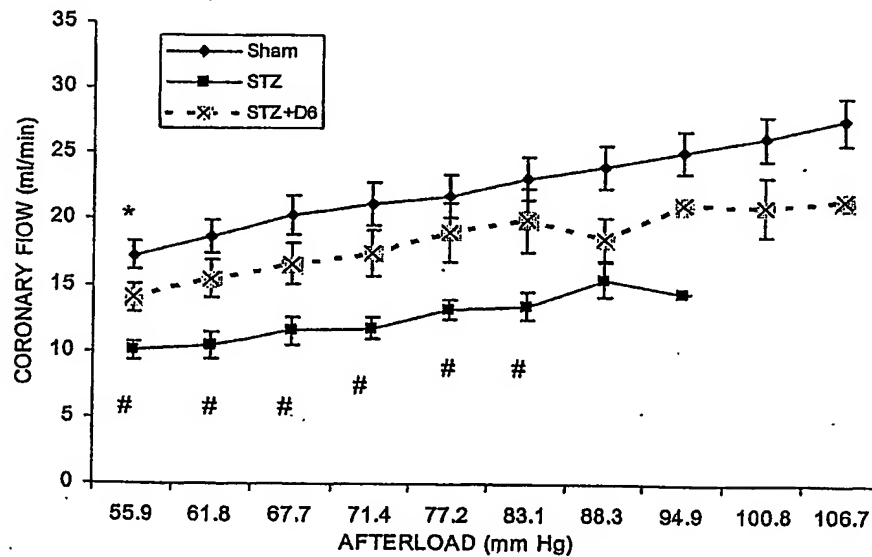
**Figure 15 Percentage of functionally surviving hearts at each afterload pressure**



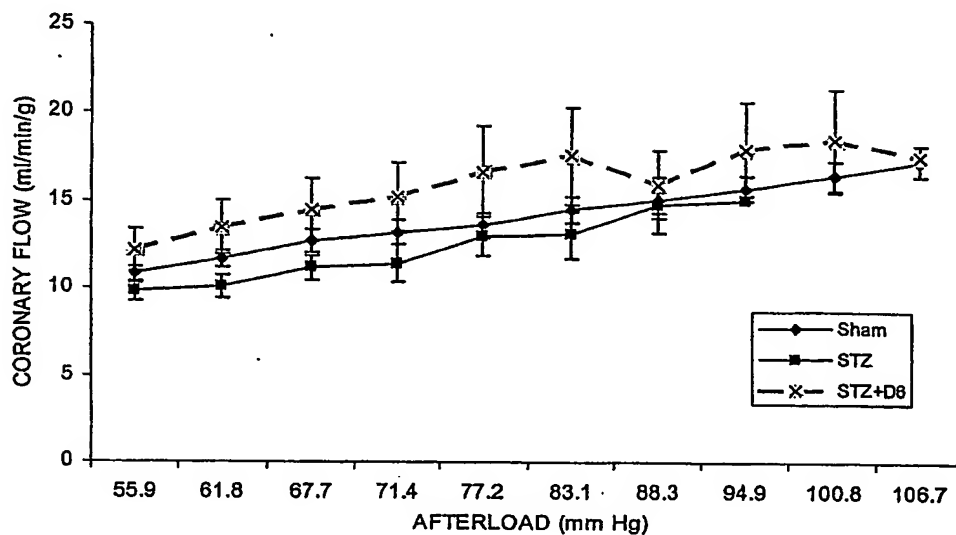
**Figure 16 Cardiac output in response to increasing afterload**



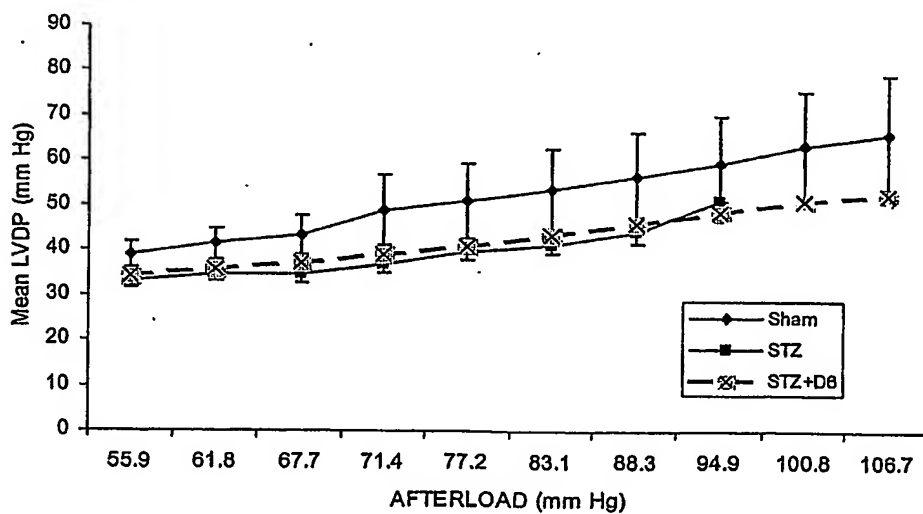
**Figure 17A Absolute change in coronary flow in response to increasing afterload**



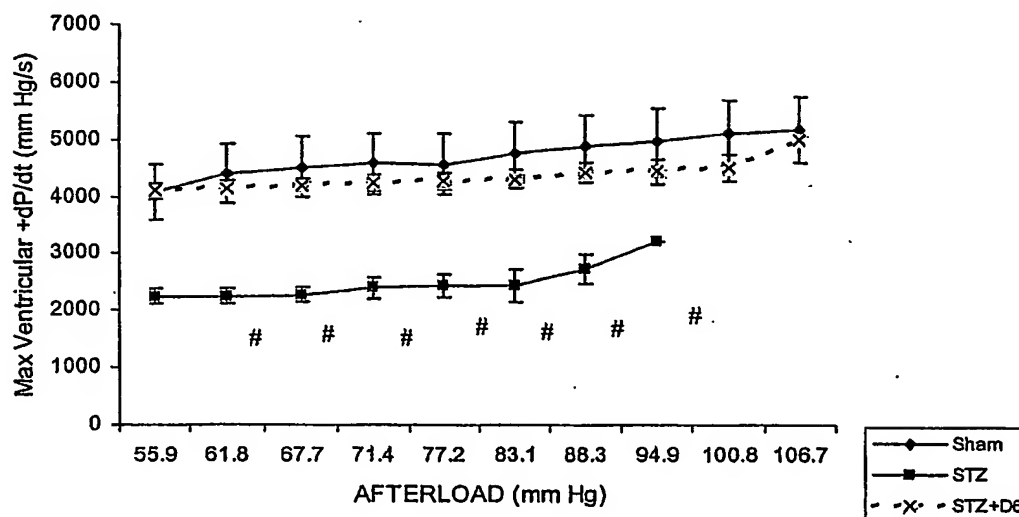
**Figure 17B Change in coronary flow in response to increasing afterload normalized to heart weight**



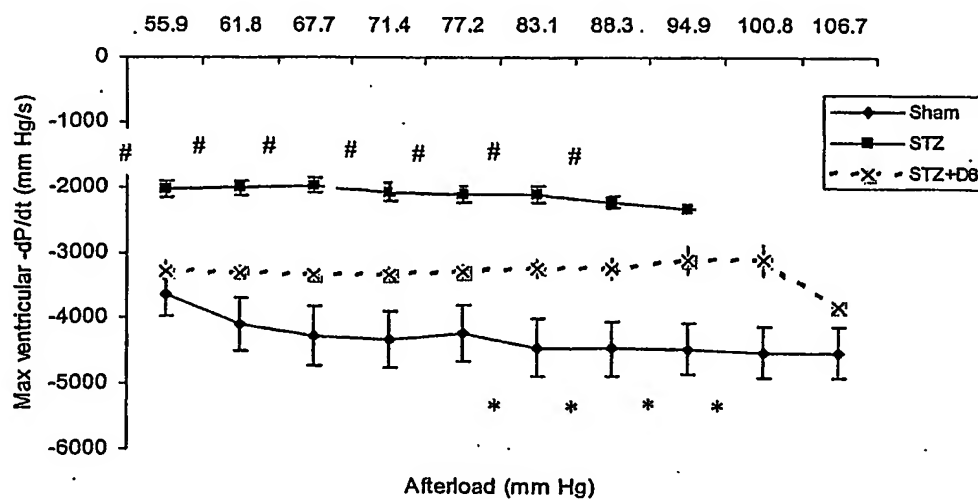
**Figure 18 Mean left ventricular developed pressure (MLVDP) in response to increasing afterload**



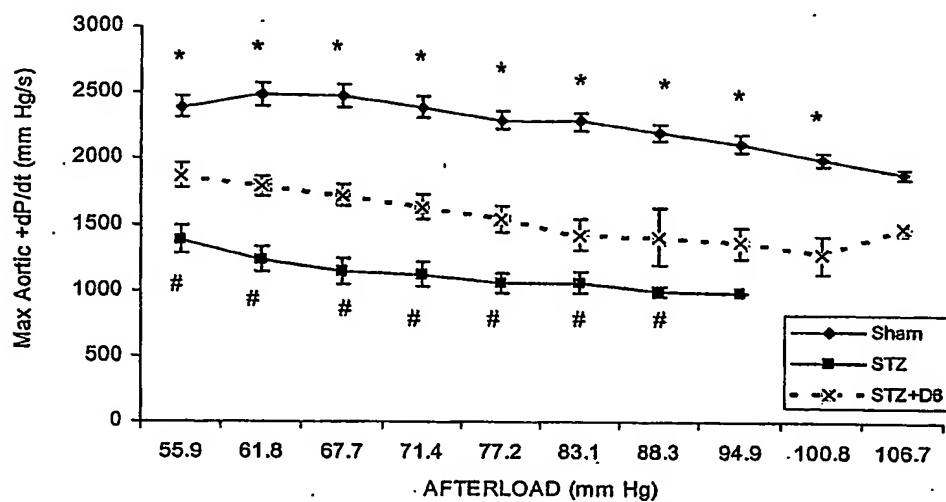
**Figure 19. Maximal rate of positive change in ventricular pressure (contraction) in response to increasing afterload**



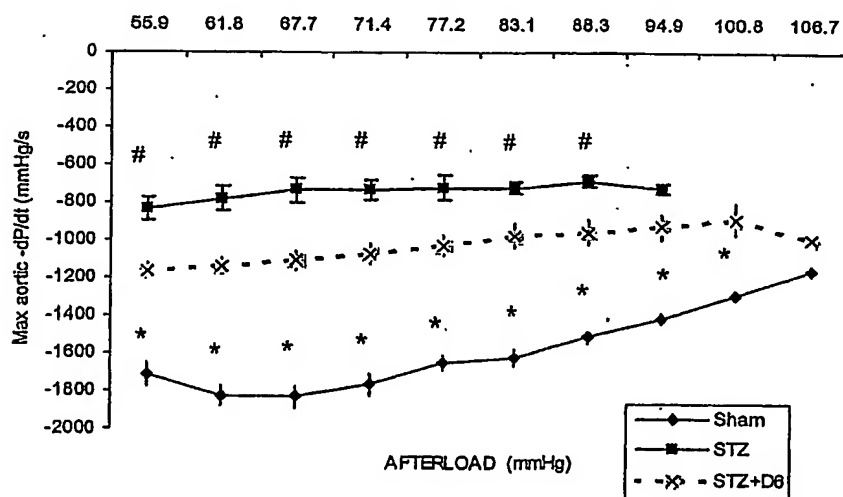
**Figure 20. Maximal rate of decrease in ventricular pressure (relaxation) in response to increasing afterload**



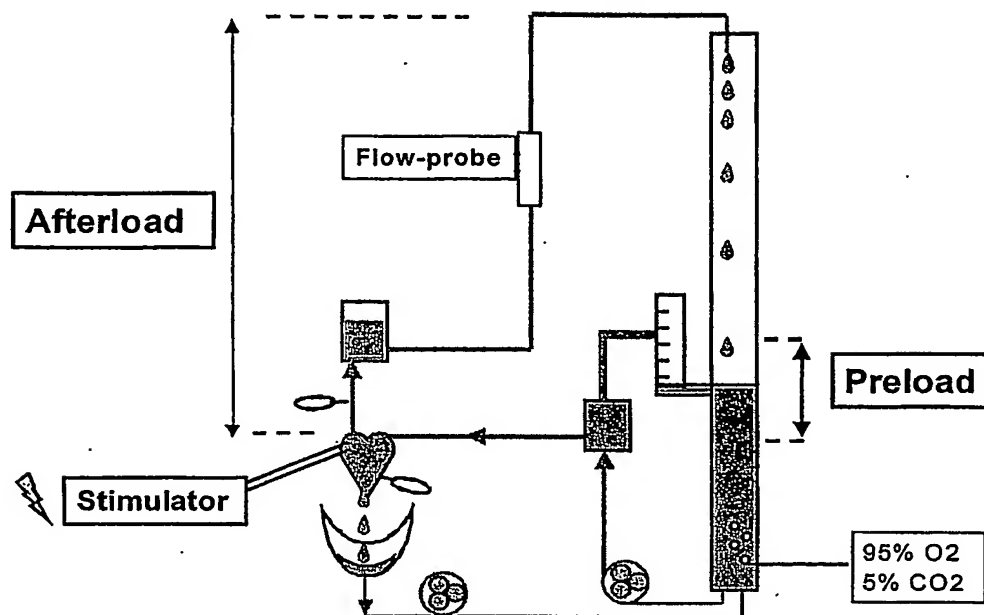
**Figure 21 Maximal rate of positive change in aortic pressure in response to increasing afterload**



**Figure 22. Maximal rate of decrease in aortic pressure in response to increasing afterload**

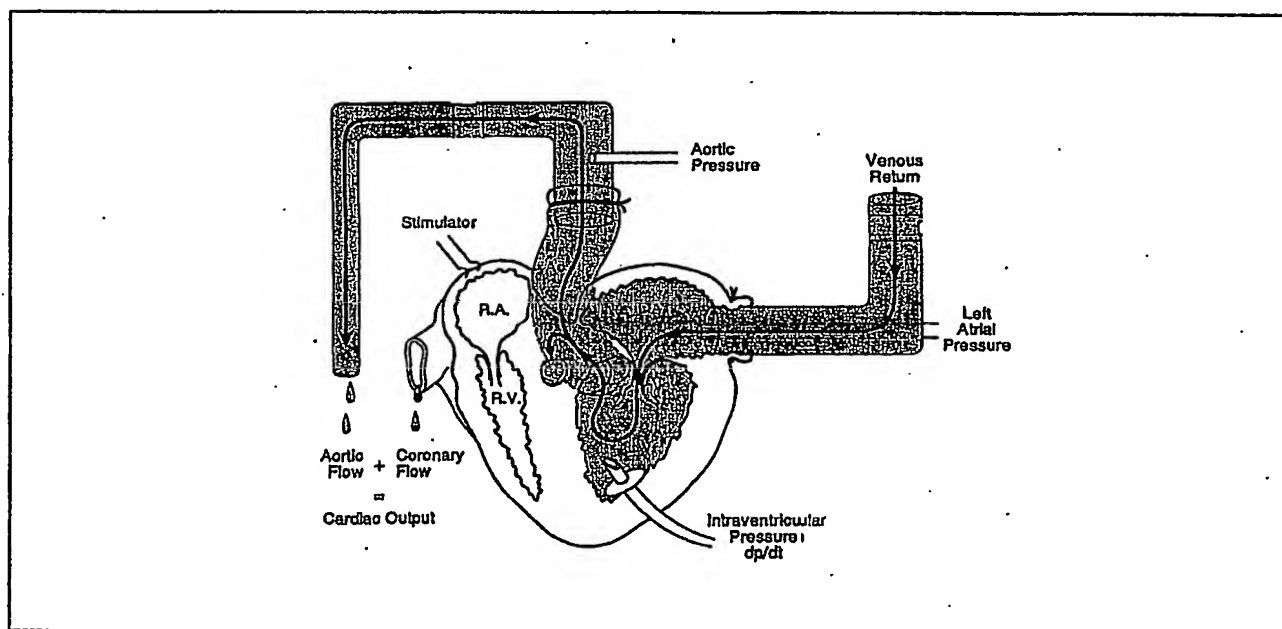


**Figure 23A Apparatus for working heart**

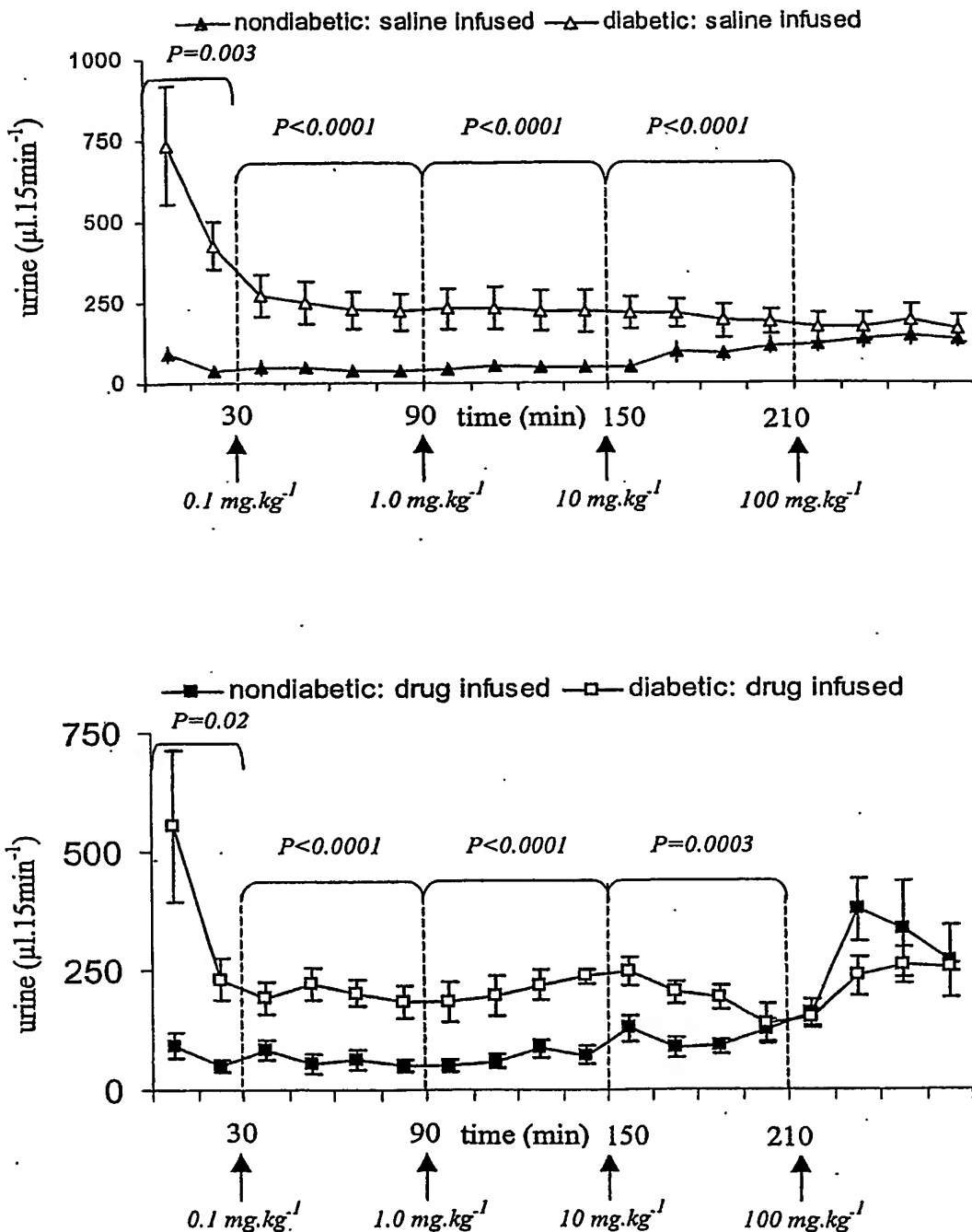


○ Pressure transducers

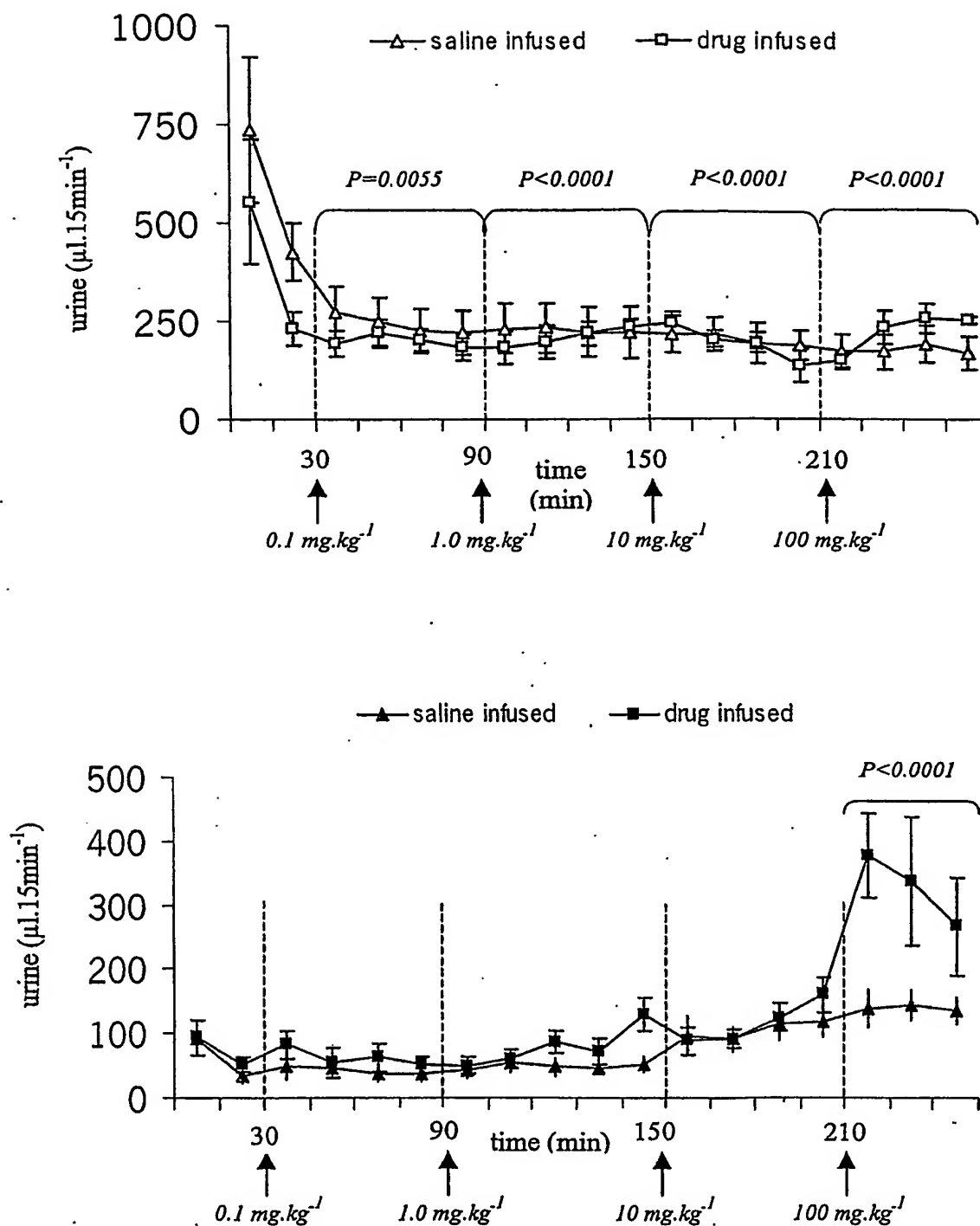
**Figure 23B Heart in more detail**







**Fig. 24.** Urine excretion in diabetic and nondiabetic animals in response to increasing doses of trientine (*bottom*; 0.1, 1.0, 10, 100 mg.kg<sup>-1</sup> in 75  $\mu\text{l}$  saline followed by 125  $\mu\text{l}$  saline flush injected at time shown by arrow) or an equivalent volume of saline (*top*). Each point represents a 15 min urine collection period (see Methods for details). Error bars show SEM and  $P$  values are stated if significant ( $P < 0.05$ ).



**Fig. 25.** Urine excretion in diabetic (*top*) and nondiabetic (*bottom*) rats receiving increasing doses of trientine (0.1, 1.0, 10, 100  $\text{mg} \cdot \text{kg}^{-1}$  in 75  $\mu\text{l}$  saline followed by 125  $\mu\text{l}$  saline flush injected at time shown by arrow) or an equivalent volume of saline. Each point represents a 15 min urine collection period (see Methods for details). Error bars show SEM and  $P$  values are stated if significant ( $P < 0.05$ ).

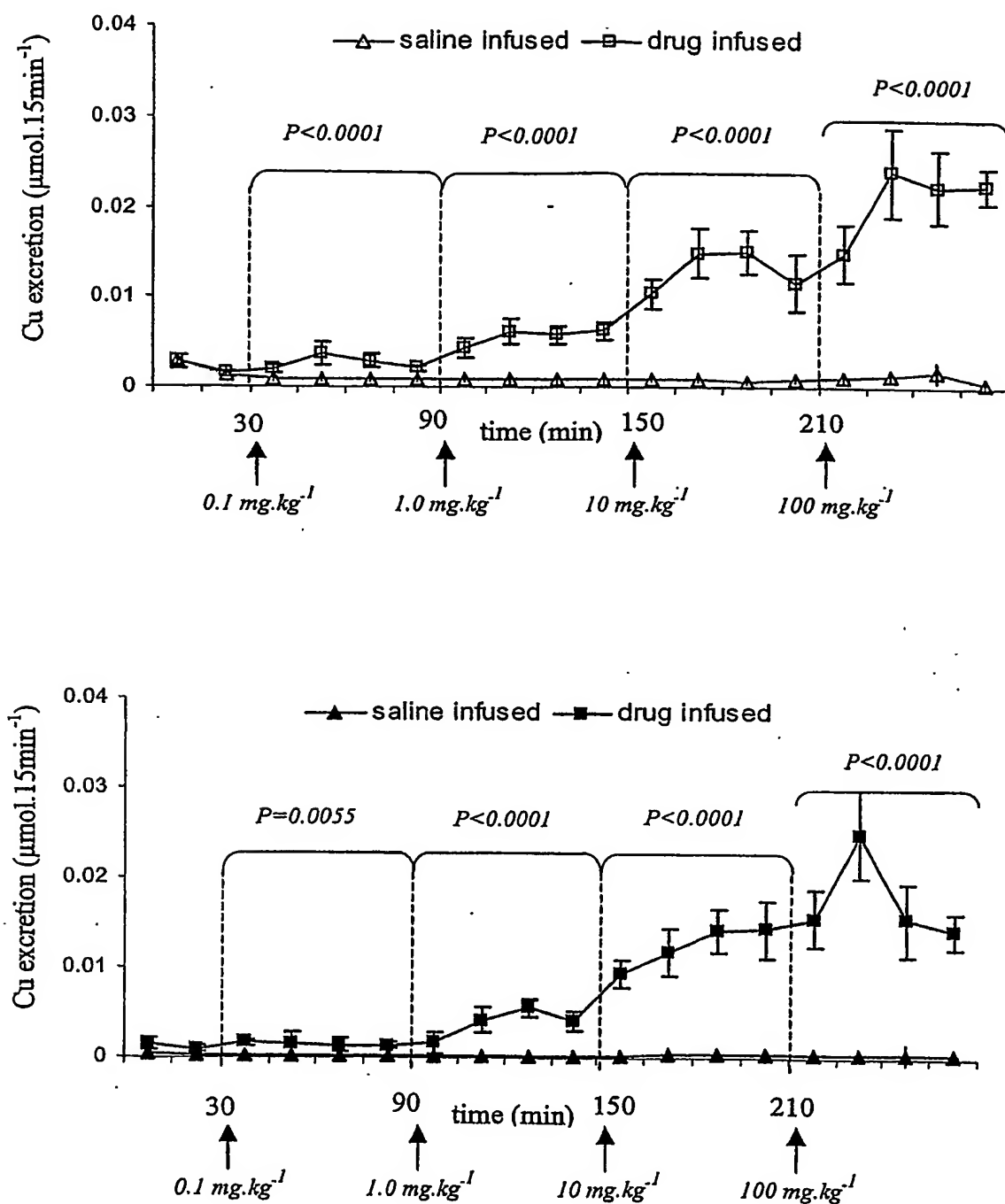


Fig. 26. Copper excretion in urine of diabetic (*top*) and nondiabetic (*bottom*) rats receiving increasing doses of trientine (0.1, 1.0, 10, 100 mg.kg<sup>-1</sup> in 75  $\mu$ l saline followed by 125  $\mu$ l saline flush injected at time shown by arrow) or an equivalent volume of saline. Each point represents a 15 min urine collection period (see Methods for details). Error bars show SEM and *P* values are stated if significant (*P* < 0.05).

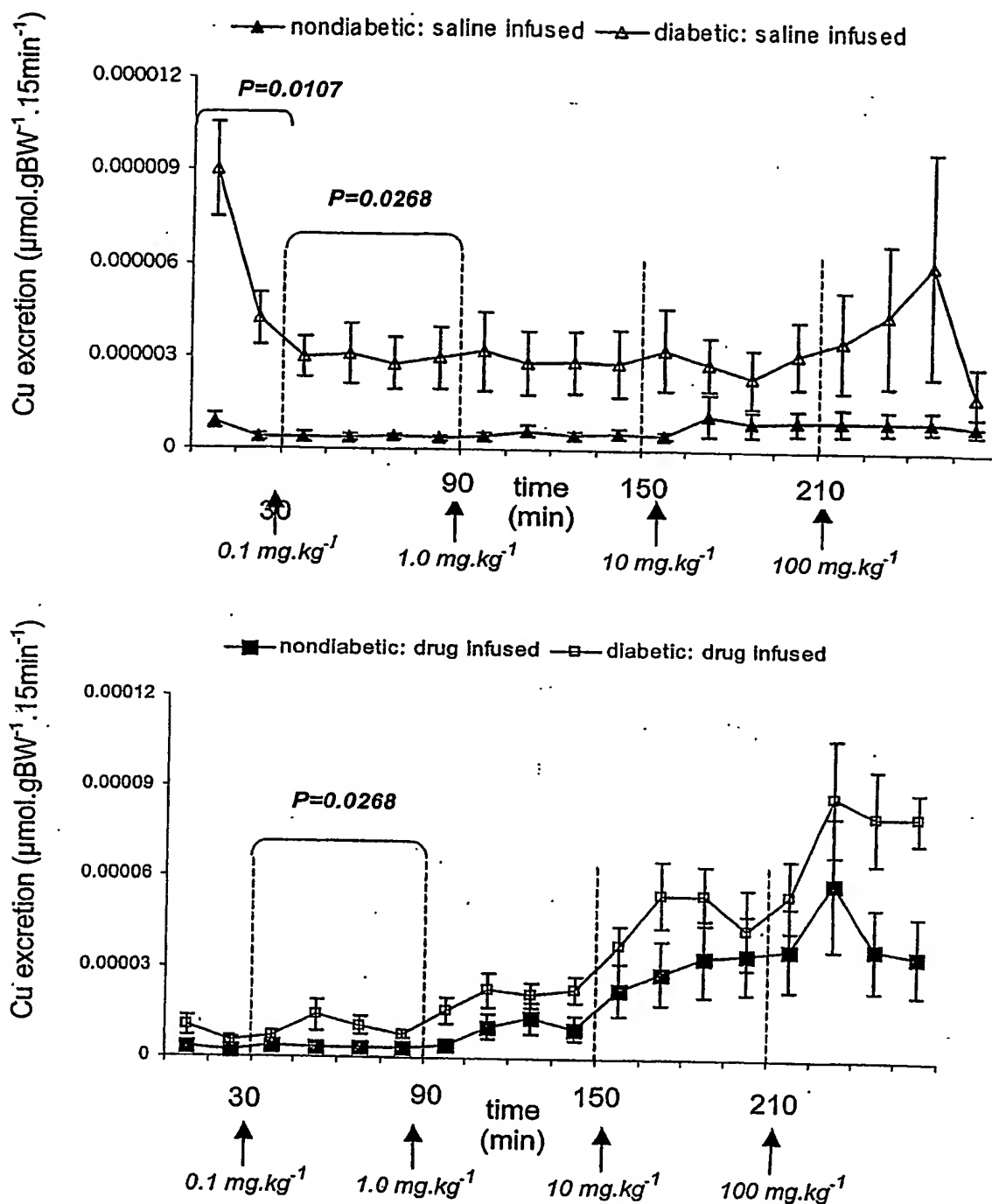
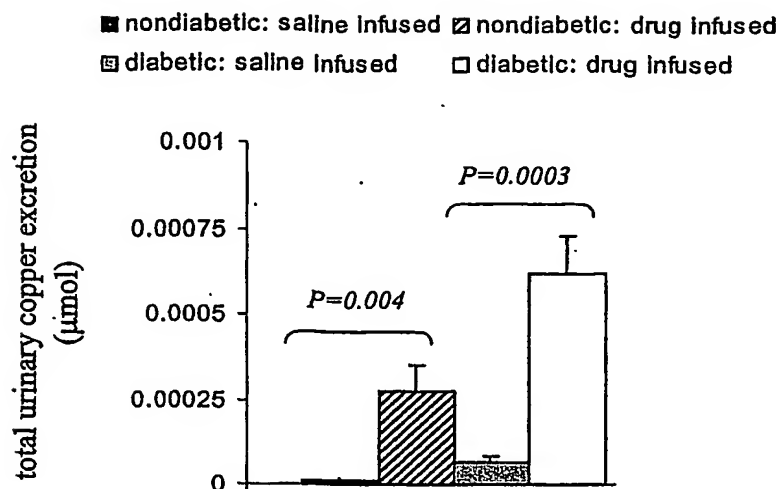
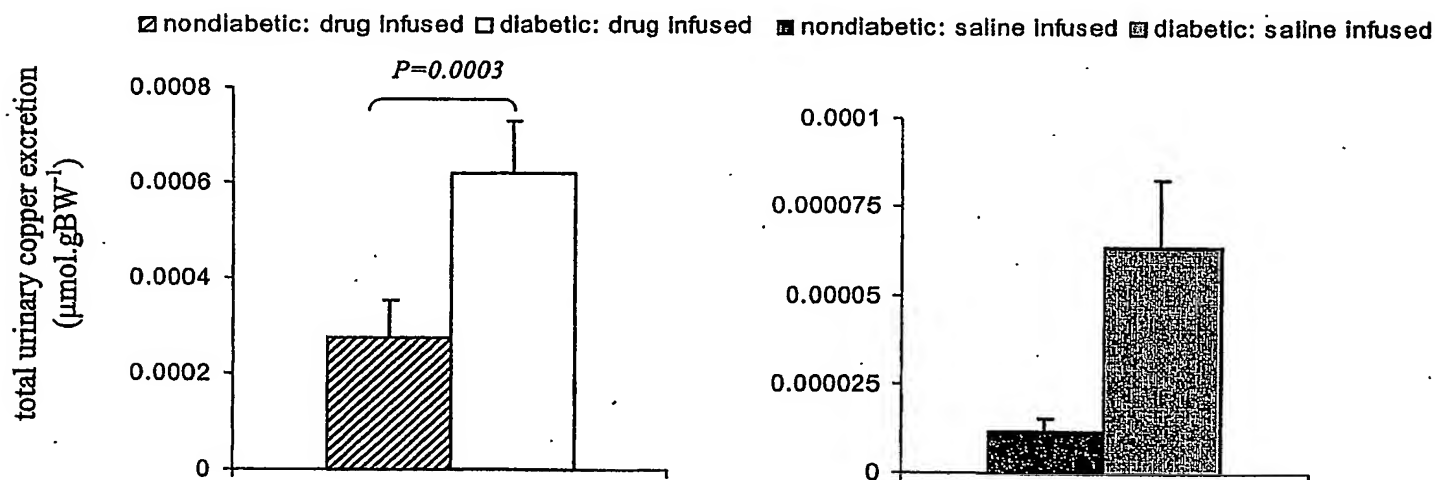


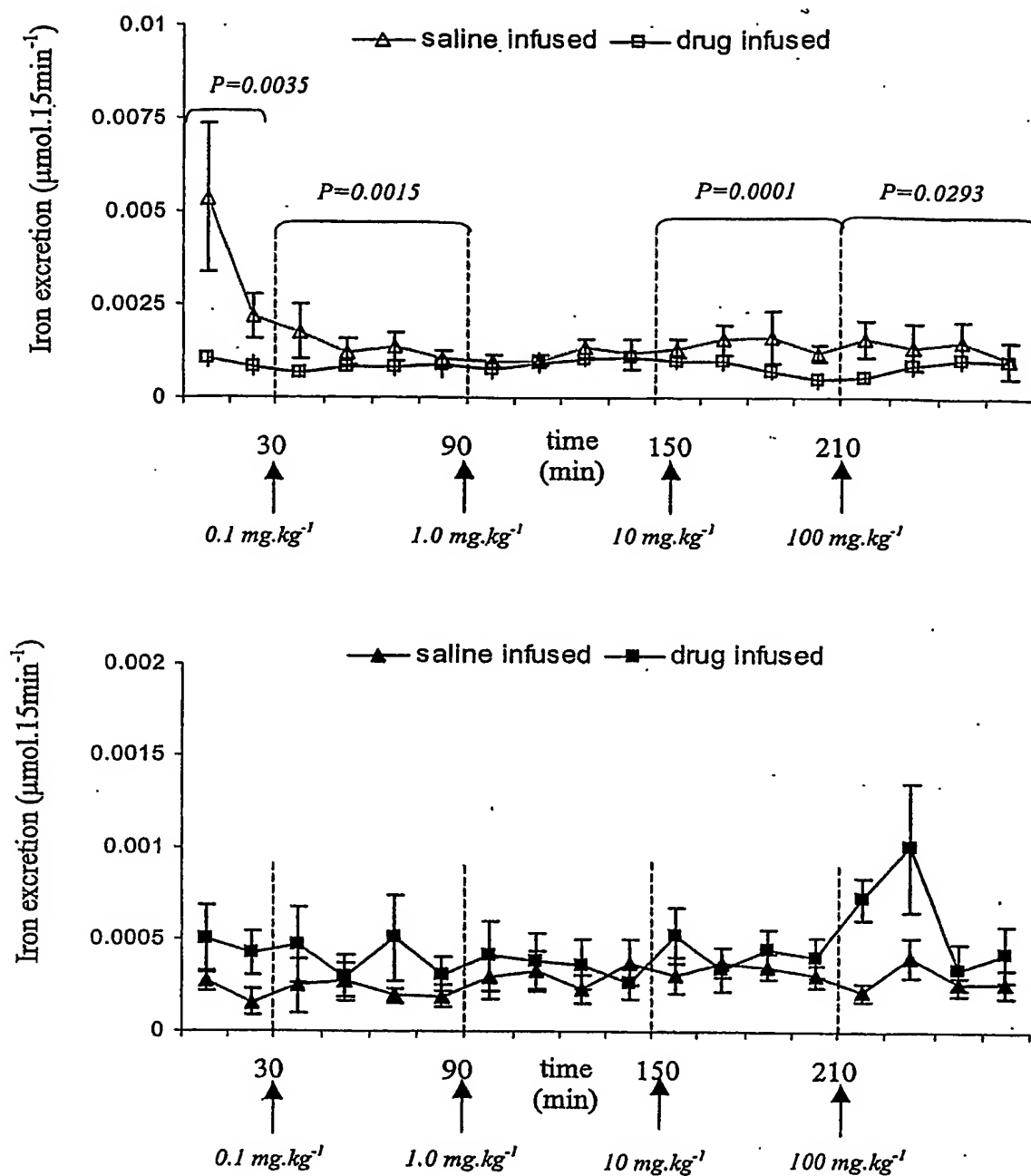
Fig. 27. Urinary copper excretion per gram of bodyweight in diabetic and nondiabetic animals in response to increasing doses of trientine (*bottom*; 0.1, 1.0, 10, 100  $\text{mg.kg}^{-1}$  in 75  $\mu\text{l}$  saline followed by 125  $\mu\text{l}$  saline flush injected at time shown by arrow) or an equivalent volume of saline (*top*). Each point represents a 15 min urine collection period (see Methods for details). Error bars show SEM and  $P$  values are stated if significant ( $P < 0.05$ ).



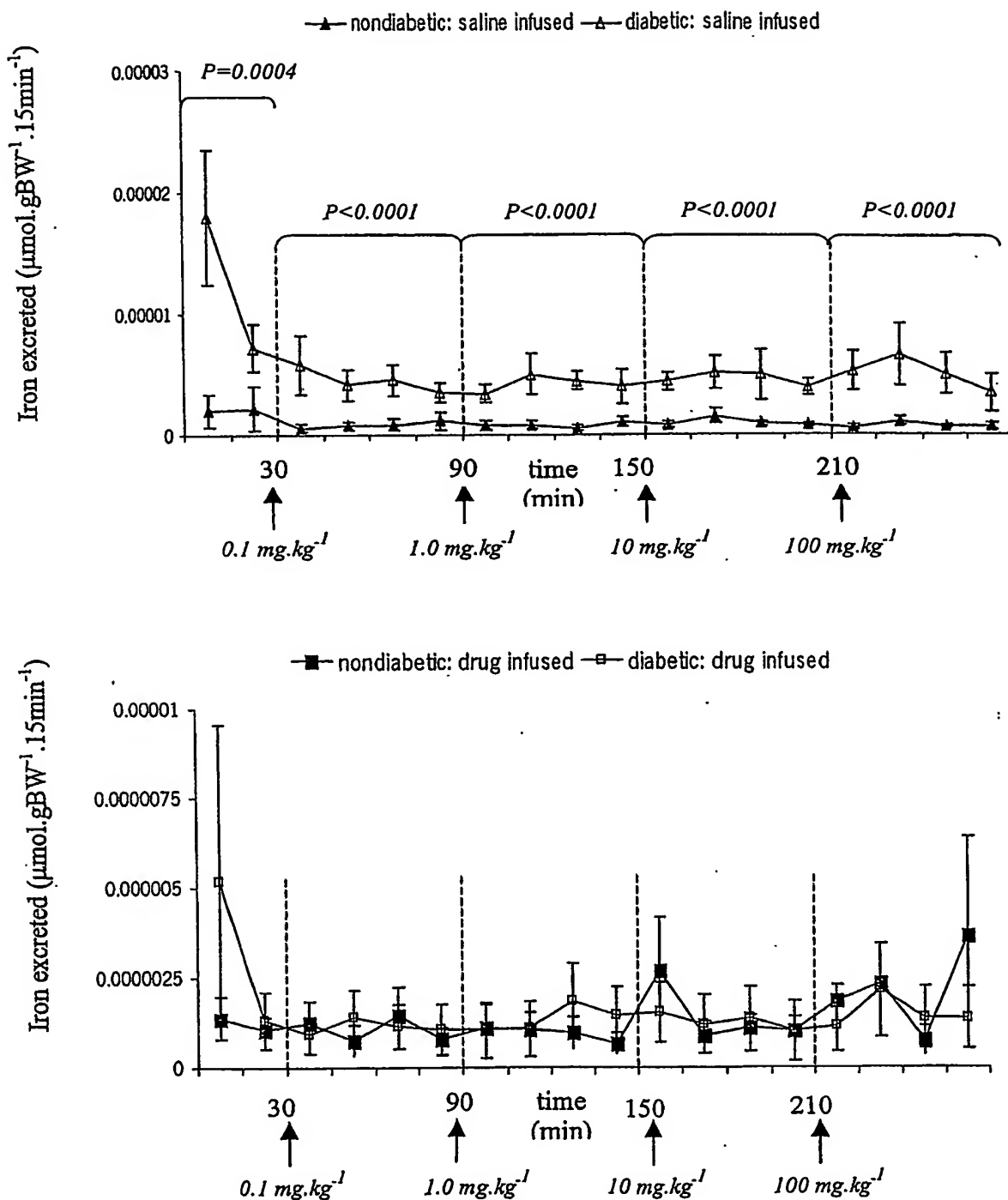
**Fig. 28.** Total urinary copper excretion ( $\mu\text{mol}$ ) in nondiabetic animals administered saline (black bar,  $n = 7$ ) or trientine (hatched bar,  $n = 7$ ) and in diabetic animals administered saline (grey bar,  $n = 7$ ) or trientine (white bar,  $n = 7$ ). Error bars show SEM and  $P$  values are stated if significant ( $P < 0.05$ ).



**Fig. 29.** Total urinary copper excretion per gram of bodyweight ( $\mu\text{g.gBW}^{-1}$ ) in animals receiving trientine (nondiabetic: hatched bar,  $n = 7$ ; diabetic: white bar,  $n = 7$ ) or saline (nondiabetic: black bar,  $n = 7$ ; diabetic: grey bar,  $n = 7$ ). Error bars show SEM and  $P$  values are stated if significant ( $P < 0.05$ ).



**Fig. 30.** Iron excretion in urine of diabetic (*top*) and nondiabetic (*bottom*) rats receiving increasing doses of trientine (0.1, 1.0, 10, 100  $\text{mg} \cdot \text{kg}^{-1}$  in 75  $\mu\text{l}$  saline followed by 125  $\mu\text{l}$  saline flush injected at time shown by arrow) or an equivalent volume of saline. Each point represents a 15 min urine collection period (see Methods for details). Error bars show SEM and *P* values are stated if significant ( $P < 0.05$ ).



**Fig. 31.** Urinary iron excretion per gram of bodyweight in diabetic and nondiabetic animals in response to increasing doses of trientine (*bottom*; 0.1, 1.0, 10, 100  $\text{mg.kg}^{-1}$  in 75  $\mu\text{l}$  saline followed by 125  $\mu\text{l}$  saline flush injected at time shown by arrow) or an equivalent volume of saline (*top*). Each point represents a 15 min urine collection period (see Methods for details). Error bars show SEM and  $P$  values are stated if significant ( $P < 0.05$ ).

■ nondiabetic: saline infused    ▨ nondiabetic: drug infused  
 ▩ diabetic: saline infused    □ diabetic: drug infused

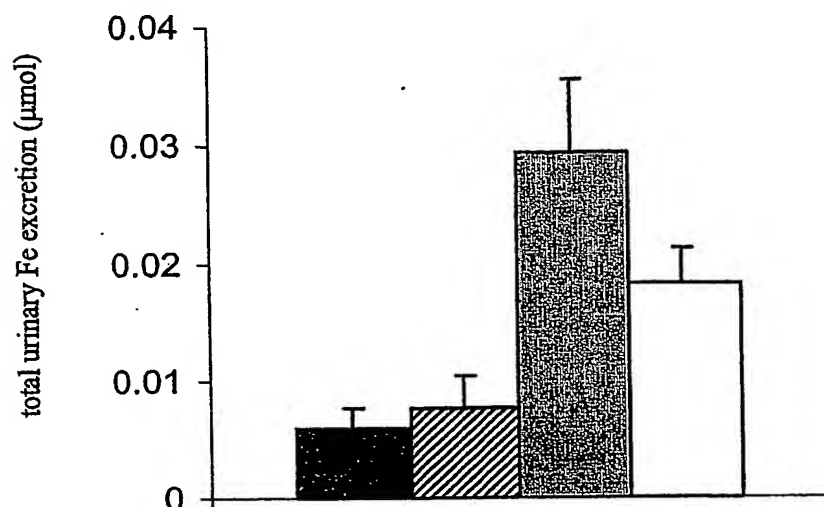


Fig. 32. Total urinary iron excretion ( $\mu\text{mol}$ ) in nondiabetic animals administered saline (black bar,  $n = 7$ ) or trientine (hatched bar,  $n = 7$ ) and in diabetic animals administered saline (grey bar,  $n = 7$ ) or trientine (white bar,  $n = 7$ ). Error bars show SEM and  $P$  values are stated if significant ( $P < 0.05$ ).

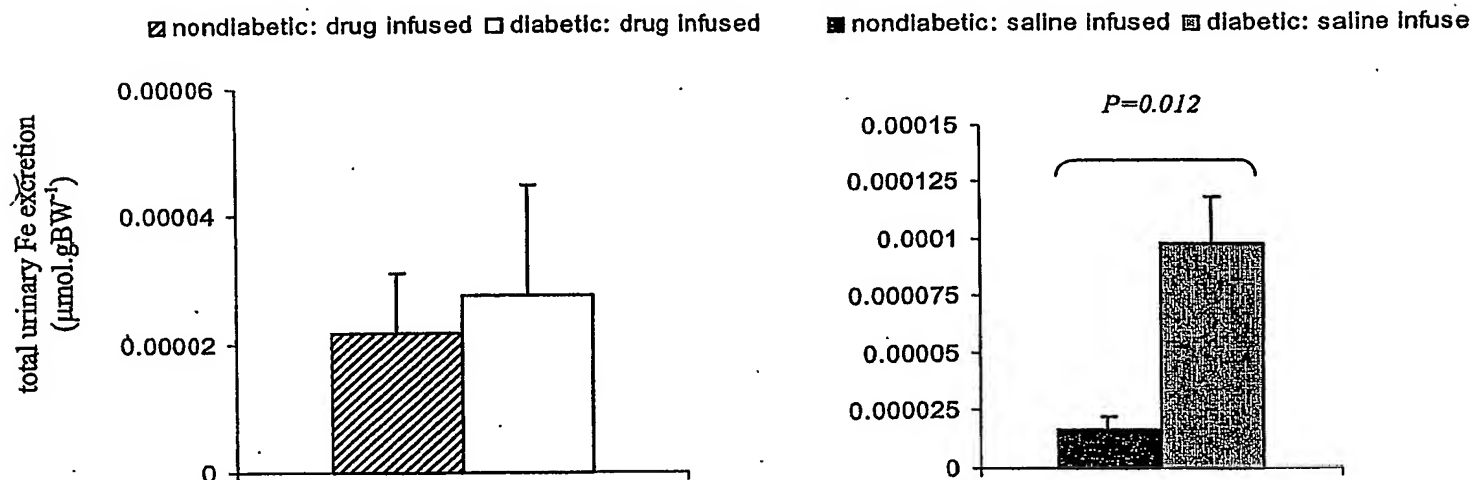
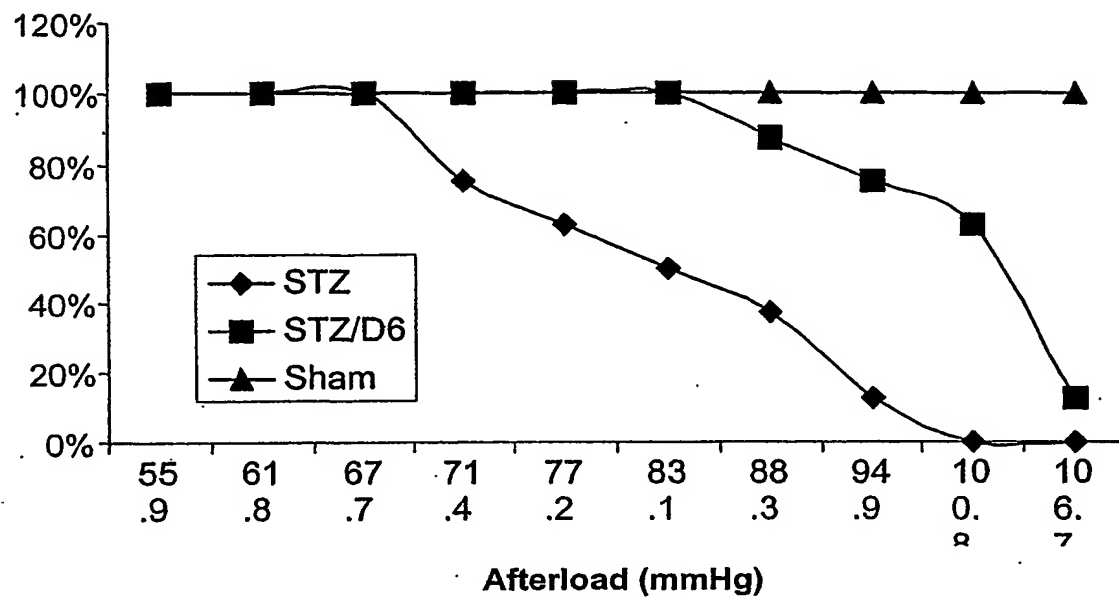


Fig. 33. Total urinary iron excretion per gram of bodyweight ( $\mu\text{g.gBW}^{-1}$ ) in animals receiving trientine (nondiabetic: hatched bar,  $n = 7$ ; diabetic: white bar,  $n = 7$ ) or saline (nondiabetic: black bar,  $n = 7$ ; diabetic: grey bar,  $n = 7$ ). Error bars show SEM and  $P$  values are stated if significant ( $P \leq 0.05$ ).



Figure 34 Percentage of surviving hearts at each afterload pressure



**FIGURE 35**

<i>Cu excretion</i>		Dose level		
Mixed Model Effects	Baseline	0.1 mg.kg <sup>-1</sup>	1.0 mg.kg <sup>-1</sup>	10 mg.kg <sup>-1</sup>
Diabetes	$F_{1,24} = 18.52$	$F_{1,24} = 19.82$	$F_{1,24} = 21.92$	$F_{1,24} = 9.93$
(normal/diabetic rats)	$P = 0.0002$	$P = 0.0002$	$P < 0.0001$	$P < 0.0001$
Drug	$F_{1,24} = 1.73$	$F_{1,24} = 24.94$	$F_{1,24} = 78.36$	$F_{1,24} = 135.36$
(drug/saline)	NS	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Interaction	$F_{1,24} = 0.16$	$F_{1,24} = 3.58$	$F_{1,24} = 7.16$	$F_{1,24} = 12.43$
	NS	NS	$P < 0.0132$	$P < 0.0017$
Sampling time (repeated measure)	$t_1, t_2$	$t_1, t_2, t_3, t_4$	$t_1, t_2, t_3, t_4$	$t_1, t_2, t_3, t_4$
<i>Fe excretion</i>		Dose level		
Mixed Model Effects	Baseline	0.1 mg.kg <sup>-1</sup>	1.0 mg.kg <sup>-1</sup>	10 mg.kg <sup>-1</sup>
Diabetes	$F_{1,23} = 12.87$	$F_{1,23} = 15.82$	$F_{1,24} = 22.68$	$F_{1,24} = 7.35$
(normal/diabetic rats)	$P = 0.0016$	$P = 0.0006$	$P < 0.0001$	$P = 0.0122$
Drug	$F_{1,23} = 8.6$	$F_{1,23} = 7.89$	$F_{1,24} = 12.23$	$F_{1,24} = 2.47$
(drug/saline)	$P = 0.0075$	$P = 0.01$	$P < 0.0019$	$P = 0.1292$
Interaction	$F_{1,23} = 12.10$	$F_{1,23} = 15.06$	$F_{1,24} = 14.07$	$F_{1,24} = 16.76$
	$P = 0.002$	$P = 0.0008$	$P = 0.001$	$P = 0.0004$
Sampling time (repeated measure)	2	$t_1, t_2, t_3, t_4$	$t_1, t_2, t_3, t_4$	$t_1, t_2, t_3, t_4$

Plasma concentration-time profiles of  
trientine after oral administration to  
four male patients<sup>1</sup>

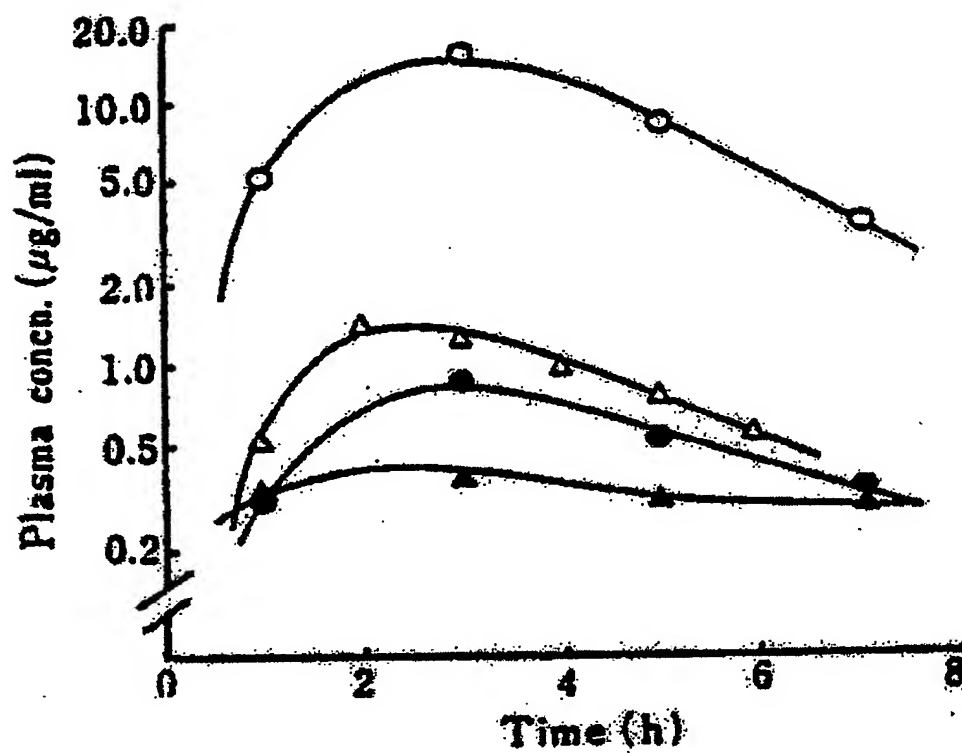


FIGURE 36

Plasma concentration-time profiles of  
trientine after oral administration to  
four female patients<sup>1</sup>

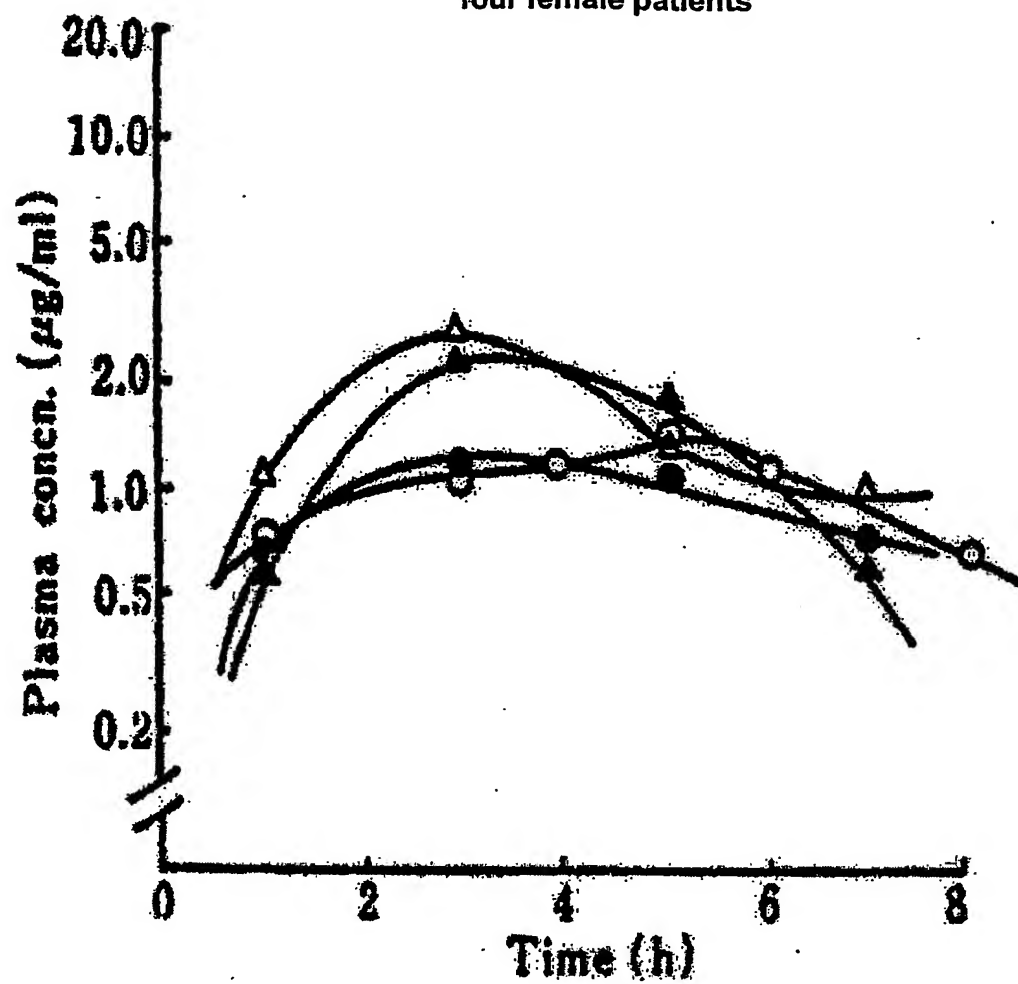


FIGURE 37

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